Docket No.: 0756-7801

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:	)
Nobuharu OHSAWA et al.	)
Application No.: 10/590,703	) Examiner: Marie R. Yamnitzky
Filed: August 25, 2006	) Group Art Unit: 1794
For: LIGHT EMITTING ELEMENT AND	)
LIGHT EMITTING DEVICE	)
	)

VERIFICATION OF TRANSLATION

Commissioner for Patents
P.O.Box 1450
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Dear Sir:

I, Akiko NORIO, C/O Semiconductor Energy Laboratory Co., Ltd. 398, Hase, Atsugi-shi, Kanagawa-ken 243-0036 Japan, a translator, herewith declare:

that I am well acquainted with both the Japanese and English Languages;

that I am the translator of the attached English translation of the Japanese Patent Application No. 2004-226382 filed on August 3, 2004; and

that to the best of my knowledge and belief the following is a true and correct English translation of the Japanese Patent Application No. 2004-226382 filed on August 3, 2004.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: this 8th day of January 2010

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[Indication of Handlings]

[Number of Prepayment Note] 002543

[Payment Amount] 16000

[List of Attachment]

[Attachment] Scope of Claim 1

[Attachment] Specification 1

[Attachment] Drawing 1

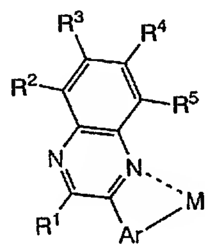
[Attachment] Abstract 1

[Document Name] Scope of Claim

[Claim 1]

An organometallic complex comprising a structure represented by a general formula (1).

[Chemical Formula 1]



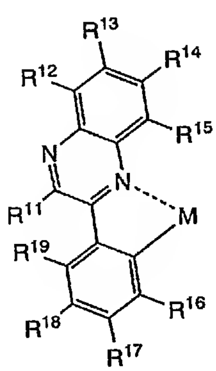
(1)

(In the formula, $R^1 \sim R^5$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is one of an aryl group and a heterocyclic group, and M is one of an element of Group 9 and an element of Group 10.)

[Claim 2]

An organometallic complex comprising a structure represented by a general formula (2).

[Chemical Formula 2]



(2)

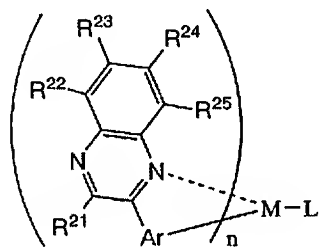
(In the formula, $R^{11} \sim R^{15}$ are individually either hydrogen, a halogen element,

an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, $R^{16} \sim R^{19}$ are individually either hydrogen, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a heterocyclic group, or an electron-withdrawing substituent, and M is an element of Group 9 or an element of Group 10.)

[Claim 3]

An organometallic complex represented by a general formula (3).

[Chemical Formula 3]



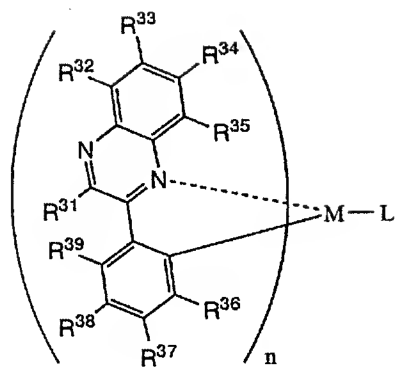
(3)

(In the formula, $R^{21} \sim R^{25}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, Ar is one of an aryl group and a heterocyclic group, M is an element of Group 9 or an element of Group 10, n = 2 when M is an element of Group 9, n = 1 when M is an element of Group 10, and L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a monoanionic bidentate chelate ligand having a phenol hydroxyl group.)

[Claim 4]

An organometallic complex represented by a general formula (4).

[Chemical Formula 4]



(4)

(In the formula, $R^{31} \sim R^{35}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group, $R^{36} \sim R^{39}$ are individually either hydrogen, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a heterocyclic group, or an electron-withdrawing substituent, M is an element of Group 9 or an element of Group 10, n = 2 when the M is an element of Group 9, n = 1 when the M is an element of Group 10, and L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a monoanionic bidentate chelate ligand having a phenol hydroxyl group.)

[Claim 5]

The organometallic complex according to claims 1 or 3, characterized in that the Ar having an electron-withdrawing substituent.

[Claim 6]

The organometallic complex according to claim 2, characterized in that at least one of the $R^{16} \sim R^{19}$ is an electron-withdrawing substituent.

[Claim 7]

The organometallic complex according to claim 4, characterized in that at least one of the $R^{36} \sim R^{39}$ is an electron-withdrawing substituent.

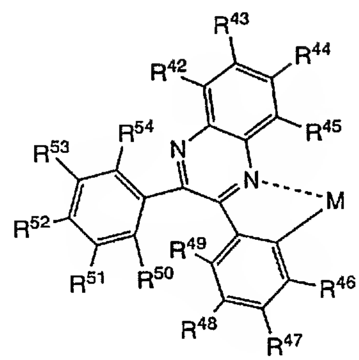
[Claim 8]

The organometallic complex according to any one of claims 5 to 7, characterized in that the electron-withdrawing substituent is any one of a halogen group, a haloalkyl group, and a cyano group.

[Claim 9]

An organometallic complex comprising a structure represented by a general formula (12).

[Chemical Formula 5]



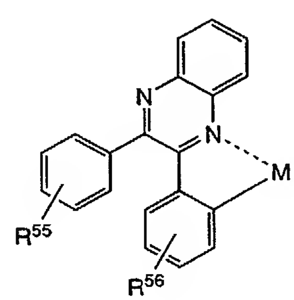
(12)

(In the formula, $R^{42} \sim R^{54}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent, and M is an element of Group 9 or an element of Group 10.)

[Claim 10]

An organometallic complex comprising a structure represented by a general formula (13).

[Chemical Formula 6]



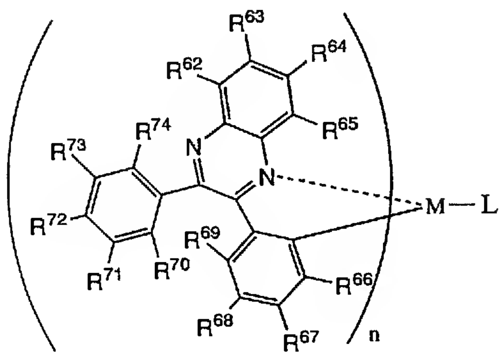
(13)

In the general formula (13), R^{55} and R^{56} are individually either a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent, and M is an element of Group 9 or an element of Group 10.

[Claim 11]

An organometallic complex represented by a general formula (14).

[Chemical Formula 7]



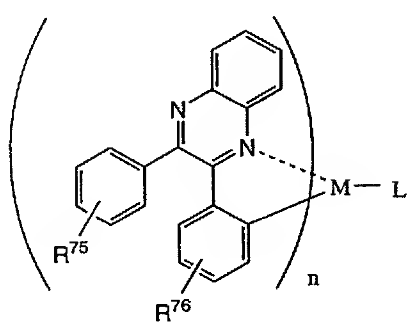
(14)

(In the formula, $R^{62} \sim R^{74}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent, M is an element of Group 9 or an element of Group 10, n = 2 when M is an element of Group 9, n = 1 when M is an element of Group 10, and L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a monoanionic bidentate chelate ligand having a phenol hydroxyl group.)

[Claim 12]

An organometallic complex represented by a general formula (15).

[Chemical Formula 8]



(15)

(In the formula, R^{75} and R^{76} are any of a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent, M is an element of Group 9 or an element of Group

10, n = 2 when M is an element of Group 9, n = 1 when M is an element of Group 10, and L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a monoanionic bidentate chelate ligand having a phenol hydroxyl group.)

[Claim 13]

The organometallic complex according to claim 9, characterized in that at least one of the $R^{46} \sim R^{49}$ is an electron-withdrawing substituent.

[Claim 14]

The organometallic complex according to claim 10, characterized in that the R^{56} is an electron-withdrawing substituent.

[Claim 15]

The organometallic complex according to claim 11, characterized in that at least one of the $R^{66} \sim R^{69}$ is an electron-withdrawing substituent.

[Claim 16]

The organometallic complex according to claim 12, characterized in that the R^{56} is an electron-withdrawing substituent.

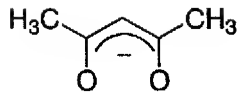
[Claim 17]

The organometallic complex according to any one of claims 9 to 16, characterized in that the electron-withdrawing substituent is any one of a halogen group, a haloalkyl group, and a cyano group.

[Claim 18]

The organometallic complex according to any one of claims 3, 4, 11, and 12, characterized in that the L is a ligand represented by any one of structural formulas (5) ~ (11).

[Chemical Formula 9]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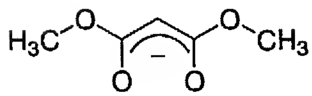
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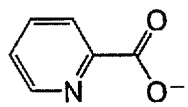
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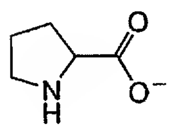
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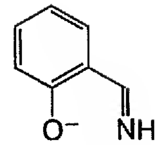
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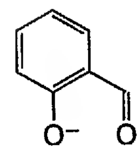
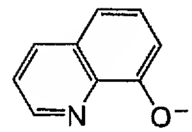

(10)


(11)

[Claim 19]

A light-emitting element comprising a layer including the organometallic complex according to any one of claims 1 to 18 between a pair of electrodes.

[Claim 20]

A light-emitting element using the organometallic complex according to any one of claims 1 to 18 as a luminescent material.

[Claim 21]

A light-emitting element characterized in that the organometallic complex according to any one of claims 1 to 18 is used as a sensitizer for fluorescent material.

[Claim 22]

A light-emitting device characterized in that the light-emitting element according to any one of claims 19 to 21 is arranged more than one.

[Claim 23]

A light-emitting device characterized in that the light-emitting element according to any one of claims 19 to 21 is used as a pixel.

[Claim 24]

An electronic device characterized in that the light-emitting device according to any one of claims 22 and 23 is used for display portion.

[Document Name] Specification

[Title of the Invention] ORGANOMETALLIC COMPLEX, LIGHT EMITTING ELEMENT AND LIGHT EMITTING DEVICE USING THE ORGANOMETALLIC COMPLEX

[Technical Field]

[0001]

The present invention relates to a material which can emit light by current excitation. In addition, the present invention relates to a light-emitting element and light-emitting device using the material.

[Background Art]

[0002]

A light-emitting element using an organic compound is an element in which a layer including an organic compound (or an organic compound film) emits light by applying an electric field. The emission mechanism is said to be as follows: when a voltage is applied to electrodes with an organic compound film interposed therebetween, an electron injected from a cathode and a hole injected from an anode are recombined in the organic compound film to form a molecular exciton, and energy is released to emit light when the molecular exciton returns to the ground state.

[0003]

In such a light-emitting element, usually, an organic compound layer is formed to be a thin film approximately 1 μm or less. In addition, since such a light-emitting element is an element in which an organic compound itself emits light, a backlight as used for a conventional liquid crystal display is not necessary. Therefore, such a light-emitting element has the big advantage of being able to be manufactured to be thin and lightweight. In addition, for example, in an organic compound film on the order of 100 to 200 nm, the time from injection of carriers to recombination is approximately several tens nanoseconds in consideration of the carrier mobility of the organic compound film, and light gets to be emitted approximately within microseconds even when the process from the recombination of the carriers to light emission is included. Therefore, it is also one of features that the response speed is quite fast. Further, since

such a light-emitting element is a carrier-injection light-emitting element, driving by a direct voltage is possible, and noise is not easily generated. As for the driving voltage, a sufficient luminance of 100 cd/m^2 is achieved at 5.5 V when an organic compound film is a uniform ultra thin film approximately 100 nm in thickness, an electrode material is selected so as to reduce the carrier injection barrier for the organic compound film, and further, a heterostructure (a two-layer structure here) is introduced (for example, refer to Non-Patent Reference 1).

[0004]

In addition to such element characteristics such as slimness, lightweight, high-speed response, and direct-current low-voltage driving, it can be also said to be one of big advantages that the luminescent color of a light-emitting element using an organic compound is rich in variation, and the factor is the variety of organic compound themselves. Namely, the flexibility of being able to develop materials for various luminescent colors by molecular design (for example, introduction of a substituent) or the like produces richness of colors. It can be said that the biggest application field of a light-emitting element utilizing this richness of colors is a full-color flat-panel display because there are a lot of organic compounds capable of emitting light's primary colors of red, green, and blue, and thus, full-color images can be achieved easily by patterning of the organic compounds.

[0005]

It can be said that the above-described element characteristics such as slimness, lightweight, high-speed response, and direct-current low-voltage driving are also appropriate characteristics for a flat-panel display. However, in recent years, the use of not fluorescent materials but phosphorescent materials has been tried as an attempt to further improve a luminous efficiency. In the case of a light-emitting element using an organic compound, luminescence is produced when a molecular exciton returns to the ground state, where the luminescence can be luminescence (fluorescence) from an excited singlet state (S^*) or luminescence (phosphorescence) from an excited triplet state (T^*). When a fluorescent material is used, only luminescence (fluorescence) from S^* contributes.

[0006]

However, it is believed that the statistical generation ratio between S^* and T^* of a light-emitting element is $S^* : T^* = 1 : 3$ (for example, refer to Non-Patent Reference 2). Accordingly, in the case of a light-emitting element using a fluorescent material, the theoretical limit of the internal quantum efficiency (the ratio of generated photons to injected carriers) is considered to be 25 % on the ground of being $S^* : T^* = 1 : 3$. In other words, in the case of a light-emitting element using a fluorescent material, at least 75 % of injected carriers are wasted uselessly.

[0007]

Conversely, it is believed that the luminous efficiency is improved (simply 3 to 4 times) when luminescence from T^*, that is, phosphorescence can be used. However, in the case of a commonly used organic material, luminescence (phosphorescence) from T^* is not observed at room temperature, and normally, only luminescence (fluorescence) from S^* is observed. This is because the ground state of an organic compound is normally a singlet ground state (S_0), and thus, $T^* \rightarrow S_0$ transition is a forbidden transition and $S^* \rightarrow S_0$ transition is an allowed transition. In reality, in recent years, light-emitting elements in which energy (hereinafter, referred to as "triplet excitation energy") that is emitted on returning from T^* to a ground state can be converted into luminescence have been released one after another, and the high light emission efficiency thereof has attracted attentions (for example, refer to Non-Patent Reference 3).

[0008]

In Non-Patent Reference 3, a metal complex including iridium as a central metal (hereinafter, referred to as "iridium complex") is used as a luminescent material, and it can be said to be a feature that an element of the third transition series is introduced as a central metal. This metal complex is a material (hereinafter, referred to as "triplet luminescent material") capable of converting an excited triplet state into luminescence at room temperature. As described in Non-Patent Reference 3, a light-emitting element using an organic compound capable of converting triplet excitation energy into luminescence can achieve higher internal quantum efficiency than

ever before. Further, when the higher internal quantum efficiency can be achieved, the luminous efficiency ([lm/W]) is also improved.

[0009]

However, according to the report of Non-Patent Reference 3, the half-life of luminance is approximately 170 hours when the initial luminance is controlled to be 500 cd/m^2 in constant current driving, and so, a light-emitting element using a triplet luminescent material has a problem with the lifetime. On the other hand, in the case of a light-emitting element using a singlet luminescent material, the half-life of luminance reaches several to ten thousands hours when the initial luminance is controlled to be 500 cd/m^2 in constant current driving, and so, it can be said that the light-emitting element has a practical use in terms of the lifetime.

[0010]

Accordingly, in a light-emitting element using a triplet luminescent material, an element that can be driven for a long time is desired. This is because a light-emitting element that is high in luminous efficiency and has a long lifetime can be obtained.

[Non-Patent Reference 1]

C. W. Tang, et al., Applied Physics Letters, vol. 51, No. 12, pp. 913-915 (1987)

[Non-Patent Reference 2]

Tetsuo TSUTSUI, Textbook for the 3rd Workshop, Division of Molecular Electronics and Bioelectronics, Japan Society of Applied Physics, p. 31 (1993)

[Non-Patent Reference 3]

Tetsuo TSUTSUI, et al., Japanese Journal of Applied Physics, vol. 38, pp. L1502-L1504 (1999)

[Disclosure of Invention]

[Problems to be Solved by the Invention]

[0011]

It is an object of the present invention to provide a material capable of emitting phosphorescence. In addition, it is another object of the present invention to provide a

light-emitting element with good chromaticity.

[Means for Solving the Problem]

[0012]

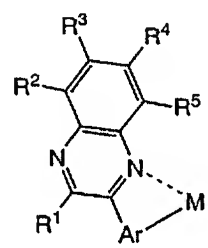
As a result of painstaking research by the present inventors, it is found that an organometallic complex including a structure as represented by any one of general formulas (1), (2), (12) or (13), or an organometallic complex as represented by any one of general formulas (3), (4), (14) or (15) can emit phosphorescence.

[0013]

One aspect of the present invention is an organometallic complex including a structure represented by a general formula (1).

[0014]

[Chemical Formula 1]



(1)

[0015]

In the general formula (1), $R^1 \sim R^5$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group. Ar represents an aryl group or a heterocyclic group and is preferably either an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent. In addition, M is one of an element of Group 9 and an element of Group 10.

[0016]

Since Ar is a group having an electron-withdrawing substituent, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

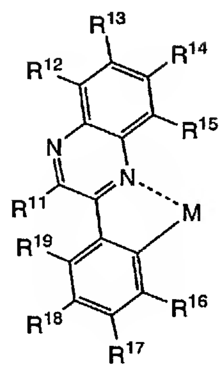
[0017]

One aspect of the present invention is an organometallic complex including a

structure represented by a general formula (2).

[0018]

[Chemical Formula 2]



(2)

[0019]

In the general formula (2), R^{11} ~ R^{15} are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group. R^{16} ~ R^{19} are individually either hydrogen, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent and at least one of R^{16} ~ R^{19} is preferably the electron-withdrawing substituent. In addition, M is one of an element of Group 9 and an element of Group 10.

[0020]

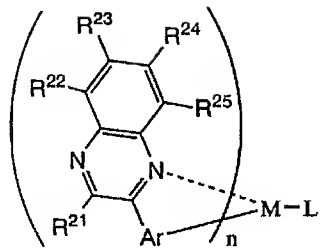
Since any one of R^{16} ~ R^{19} is a group having an electron-withdrawing substituent, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

[0021]

One aspect of the present invention is an organometallic complex represented by a general formula (3).

[0022]

[Chemical Formula 3]



(3)

[0023]

In the general formula (3), $R^{21} \sim R^{25}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group. Ar represents an aryl group or a heterocyclic group and is preferably either an aryl group having an electron-withdrawing substituent or a heterocyclic group having an electron-withdrawing substituent. In addition, M is one of an element of Group 9 and an element of Group 10. In addition, n is 2 when M is an element belonging to Group 9, and n is 1 when M is an element belonging to Group 10. Also, L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a monoanionic bidentate chelate ligand having a phenol hydroxyl group.

[0024]

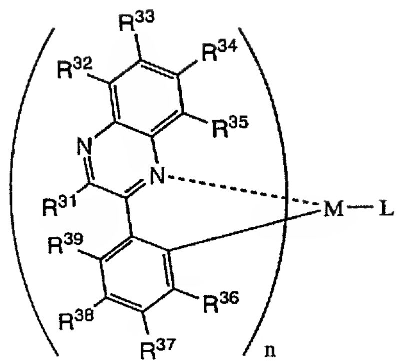
Since Ar is a group having an electron-withdrawing substituent, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

[0025]

One aspect of the present invention is an organometallic complex represented by a general formula (4).

[0026]

[Chemical Formula 4]



(4)

[0027]

In the formula (4), $R^{31} \sim R^{35}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group. $R^{36} \sim R^{39}$ are individually either hydrogen, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a heterocyclic group, or an electron-withdrawing substituent and at least one of $R^{36} \sim R^{39}$ is preferably the electron-withdrawing substituent. M is one of an element of Group 9 and an element of Group 10. In addition, n is 2 when M is an element belonging to Group 9, and n is 1 when M is an element belonging to Group 10. Also, L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a monoanionic bidentate chelate ligand having a phenol hydroxyl group.

[0028]

Since any one of $R^{36} \sim R^{39}$ is a group having an electron-withdrawing substituent, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

[0029]

In an organometallic complex having a structure represented by the general formula (1) or (2), or an organometallic complex represented by the general formula (3) or (4), an electron-withdrawing substituent is preferably any one of a halogen group, a haloalkyl group, and a cyano group. Accordingly, chromaticity and quantum efficiency of the organometallic complex are improved. In addition, a fluoro group is

preferable among a halogen group, and a trifluorometyl group is preferable among a haloalkyl group, in particular. Accordingly, electrons can be trapped efficiently.

[0030]

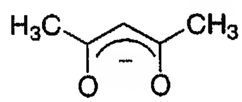
In the organometallic complex represented by the general formula (3) or (4), central metal M is preferably a heavy metal, more preferably, iridium or platinum. Accordingly, a heavy atom effect can be obtained.

[0031]

In the organometallic complex represented by the general formula (3) or (4), it is particularly preferable that L is monoanionic ligands represented by structural formulas (5) ~ (11). Since the monoanionic chelate ligands represented by the structural formulas (5) ~ (11) have high coordinative ability and can be obtained at low price, they are useful.

[0032]

[Chemical formula 5]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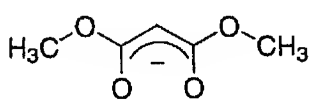
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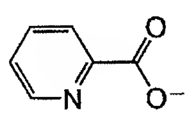
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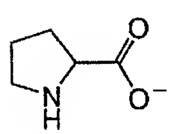
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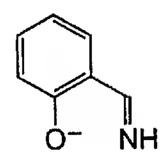
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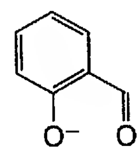
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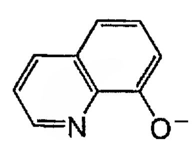

(11)

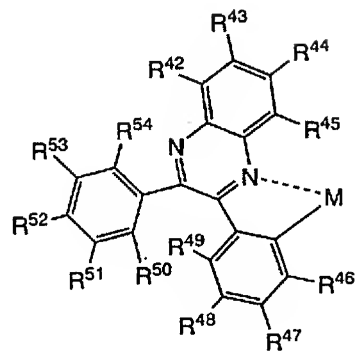
[0033]

One aspect of the present invention is an organometallic complex including a

structure represented by a general formula (12).

[0034]

[Chemical formula 6]



(12)

[0035]

In the general formula (12), $R^{42} \sim R^{54}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent. M is one of an element of Group 9 and an element of Group 10.

[0036]

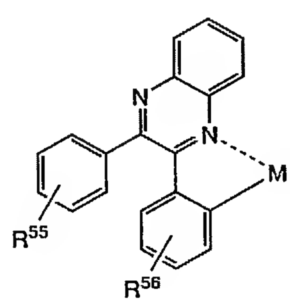
At least one of $R^{46} \sim R^{49}$ is preferably an electron-withdrawing substituent. Accordingly, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

[0037]

One aspect of the present invention is an organometallic complex including a structure represented by a general formula (13).

[0038]

[Chemical formula 7]



(13)

[0039]

In the general formula (13), R^{55} and R^{56} are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent. M is one of an element of Group 9 and an element of Group 10.

[0040]

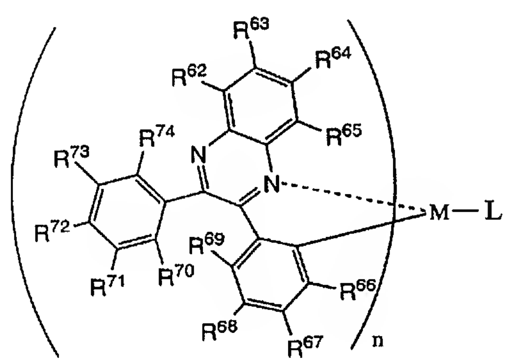
Here, R^{56} is preferably an electron-withdrawing substituent. Accordingly, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

[0041]

One aspect of the present invention is an organometallic complex represented by a general formula (14).

[0042]

[Chemical Formula 8]



(14)

[0043]

In the general formula (14), $R^{62} \sim R^{74}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent. M is one of an element of Group 9 and an element of Group 10. In addition, n is 2 when M is an element belonging to Group 9, and n is 1 when M is an element belonging to Group 10. Also, L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a

monoanionic bidentate chelate ligand having a phenol hydroxyl group.

[0044]

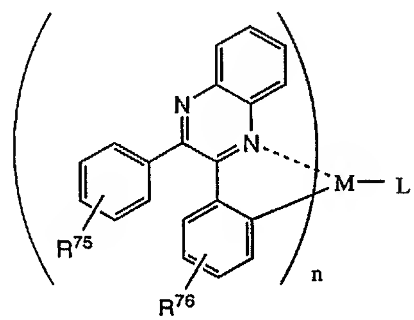
Here, at least one of $R^{66} \sim R^{69}$ is preferably an electron-withdrawing substituent. Accordingly, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

[0045]

One aspect of the present invention is an organometallic complex represented by a general formula (15).

[0046]

[Chemical Formula 9]



(15)

[0047]

In the formula (15), R^{75} and R^{76} are individually either a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent. M is one of an element of Group 9 and an element of Group 10. In addition, n is 2 when M is an element belonging to Group 9, and n is 1 when M is an element belonging to Group 10. Also, L represents any one of a monoanionic ligand having a beta-diketone structure, a monoanionic bidentate chelate ligand having a carboxyl group, and a monoanionic bidentate chelate ligand having a phenol hydroxyl group.

[0048]

Here, R^{76} is preferably an electron-withdrawing substituent. Accordingly, a phosphorescent organometallic complex having higher light emission intensity can be obtained.

[0049]

In an organometallic complex having a structure represented by the general formula (12) or (13), or an organometallic complex represented by the general formula (14) or (15), an electron-withdrawing substituent is preferably any one of a halogen group, a haloalkyl group, and a cyano group. Accordingly, chromaticity and quantum efficiency of the organometallic complex are improved. In addition, a fluoro group is preferable among a halogen group, and a trifluorometyl group is preferable among a haloalkyl group, in particular. Accordingly, electrons can be trapped efficiently.

[0050]

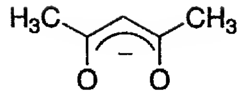
In the organometallic complex represented by the general formula (14) or (15), central metal M is preferably a heavy metal, more preferably, iridium or platinum. Accordingly, a heavy atom effect can be obtained.

[0051]

In the organometallic complex represented by the general formula (14) or (15), it is particularly preferable that L is monoanionic ligands represented by structural formulas (5) ~ (11). Since the monoanionic chelate ligands represented by the structural formulas (5) ~ (11) have high coordinative ability and can be obtained at low price, they are useful.

[0052]

[Chemical Formula 10]



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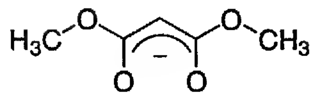

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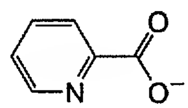

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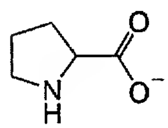

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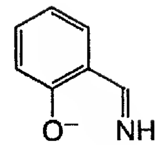

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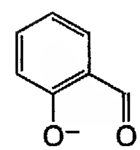

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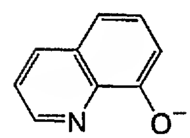


(11)

[0053]

One aspect of the present invention is an organometallic complex including a structure represented by any one of general formulas (1), (2), (12) or (13) or a light-emitting element including an organometallic complex represented by any one of general formulas (3), (4), (14) or (15).

[0054]

One aspect of the present invention is an organometallic complex having a structure represented by the general formulas (1), (2), (12) or (13) or a light-emitting device including a light-emitting element having an organometallic complex represented by any one of general formulas (3), (4), (14) or (15).

[Effect of the Invention]

[0055]

According to the present invention, an organometallic complex which can emit phosphorescence can be obtained. According to the present invention, an organometallic complex which can be used as a luminescent material or a sensitizer can be obtained.

[0056]

By using the organometallic complex according to the present invention as a luminescent material, a light-emitting element that is capable of providing red luminescence that is excellent in chromaticity can be obtained. In addition, a light-emitting element that is capable of emitting light efficiently can be obtained by using the organometallic complex according to the present invention as a sensitizer. Further, by using an organometallic complex into which an electron-withdrawing substituent is introduced in particular among organometallic complexes according to the present invention, a light-emitting element that is excellent in recombination efficiency can be obtained.

[Best Mode for Carrying Out the Invention]

[0057]

Hereinafter, one mode of the present invention will be explained. Note that the present invention can be implemented in various modes, and it is easily understood by those skilled in the art that modes and details thereof can be modified in various ways without departing from the spirit and scope of the present invention. Therefore, the present invention should not be interpreted as being limited to the description of this embodiment mode.

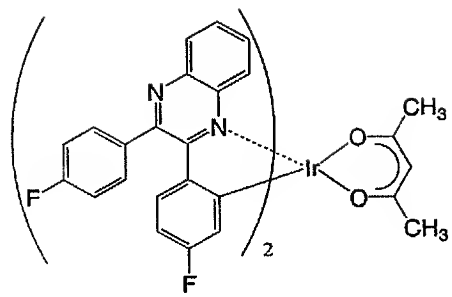
[0058]

(Embodiment Mode 1)

As one mode of the present invention, an organometallic complex represented by structural formulas (16) ~ (55) can be given. Note that the present invention is not limited to those described here.

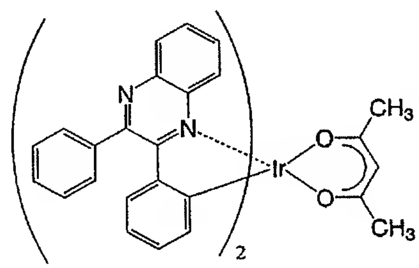
[0059]

[Chemical Formula 11]



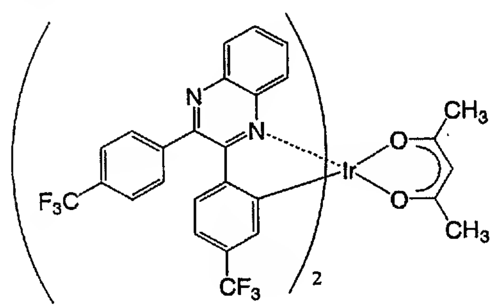
(16)

[Chemical Formula 12]



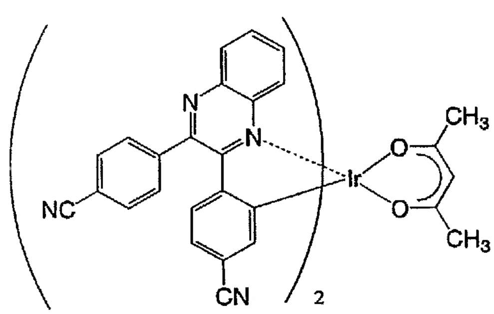
(17)

[Chemical Formula 13]



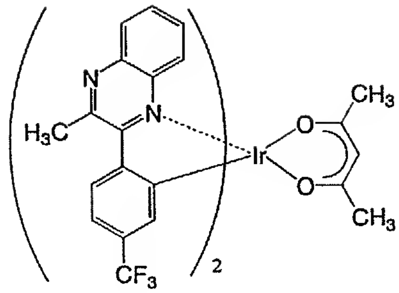
(18)

[Chemical Formula 14]



(19)

[Chemical Formula 15]



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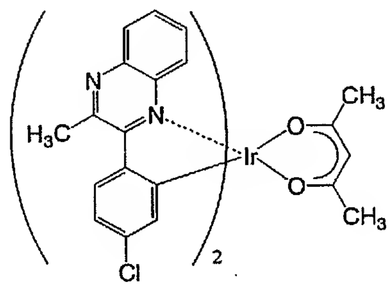
[Chemical Formula 16]



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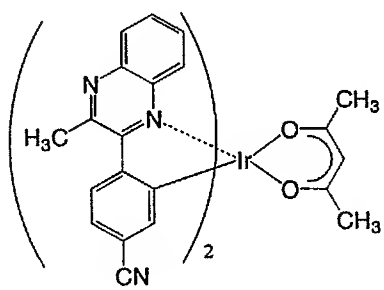
[Chemical Formula 17]



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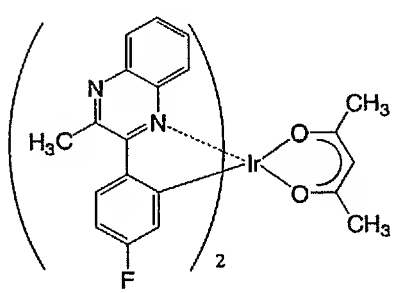
[Chemical Formula 18]



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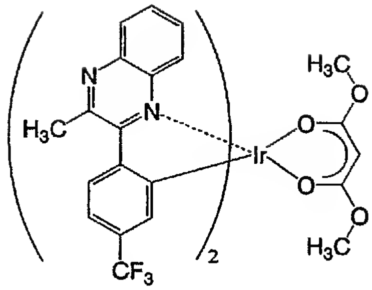
[Chemical Formula 19]



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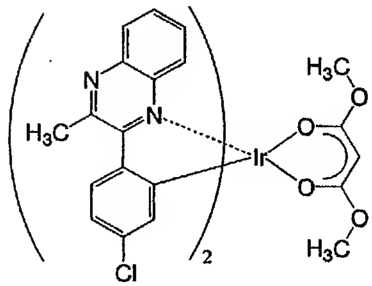
[Chemical Formula 20]



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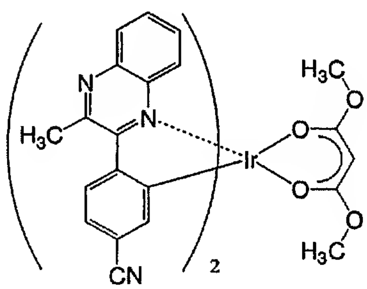
[Chemical Formula 21]



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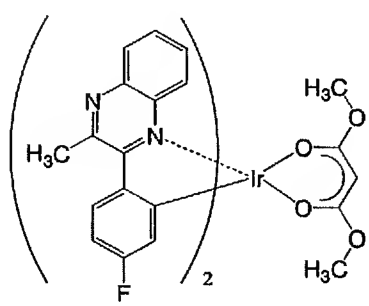
[Chemical Formula 22]



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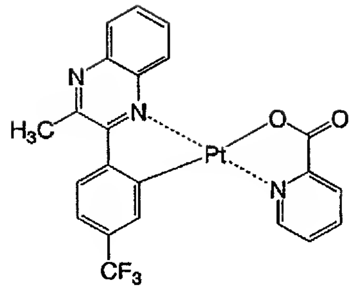
[Chemical Formula 23]



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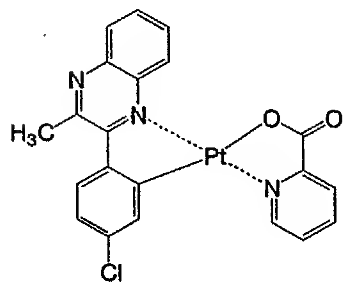

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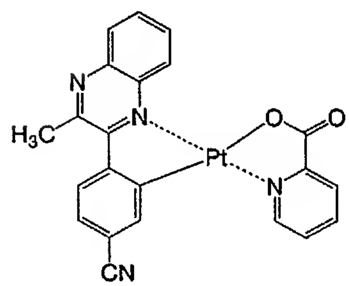
[Chemical Formula 25]



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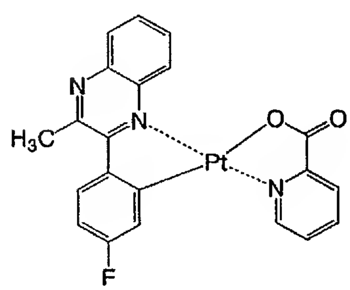

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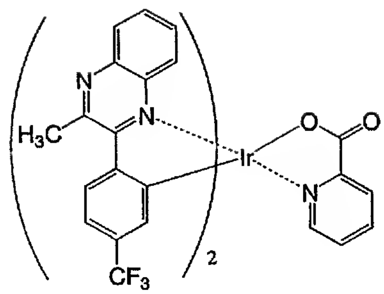

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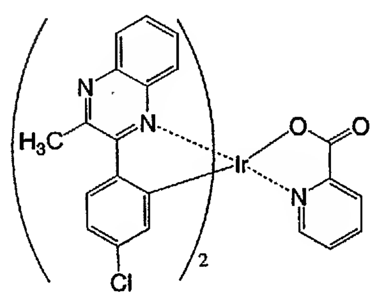
[Chemical Formula 28]



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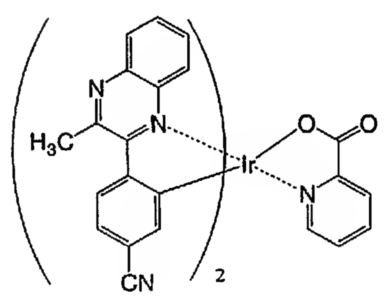

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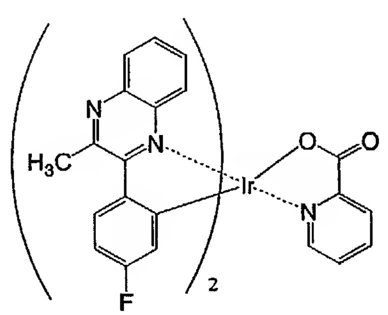

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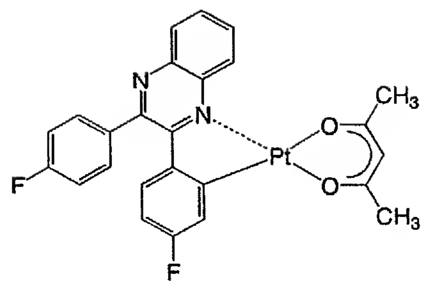

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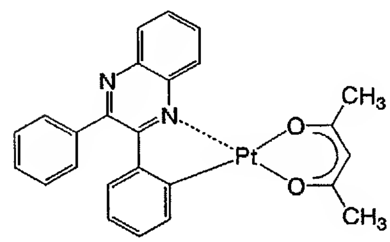

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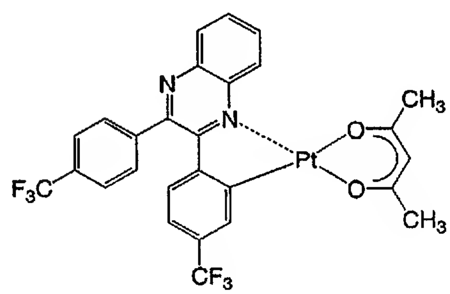

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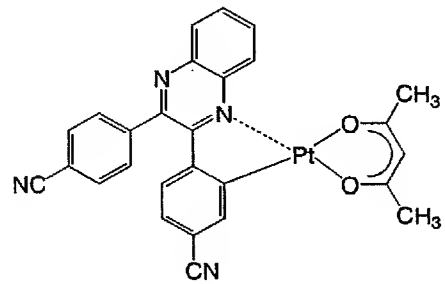

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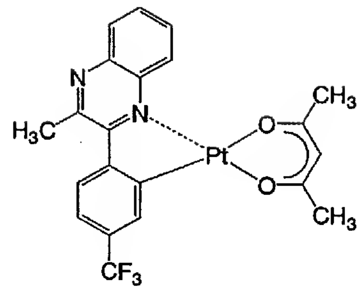

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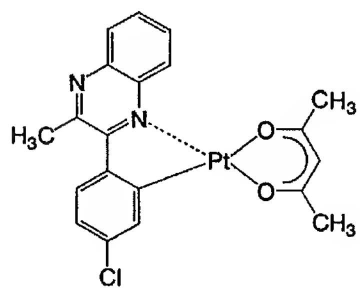

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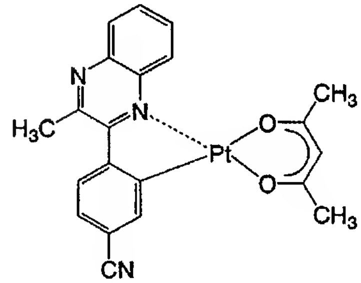

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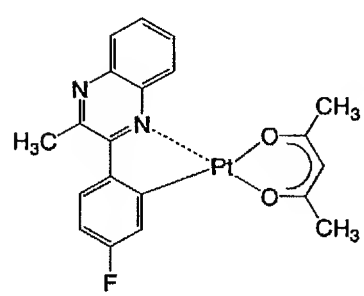

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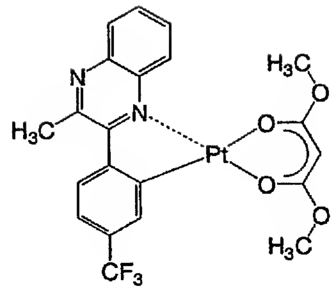

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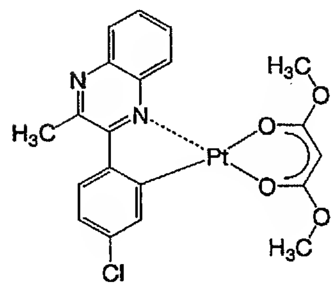

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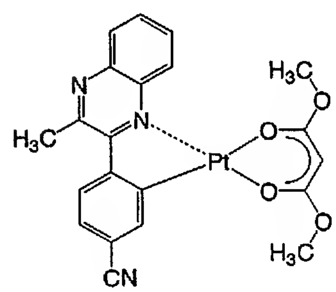

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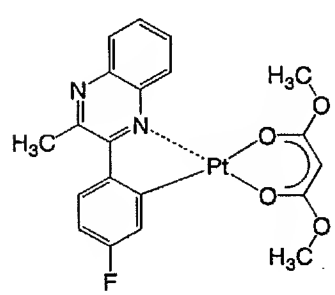

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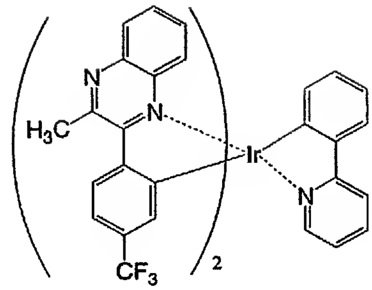

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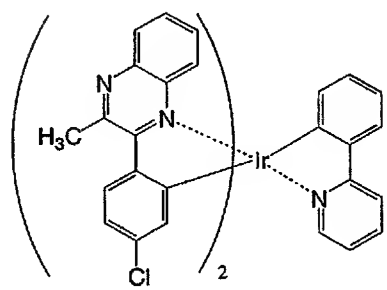

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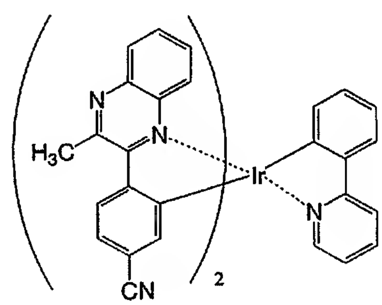

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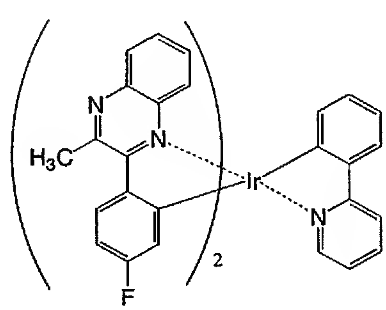

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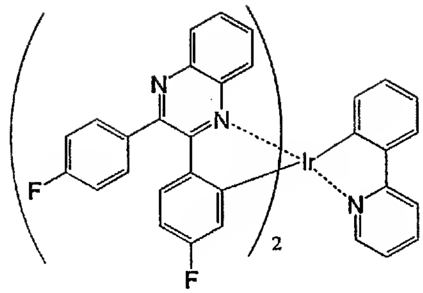

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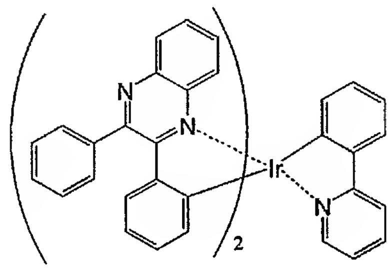

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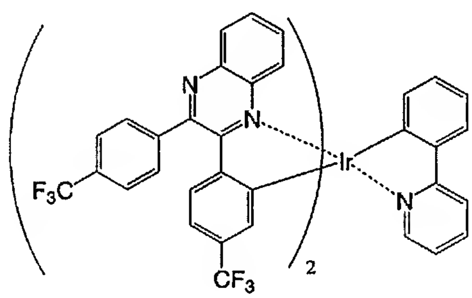
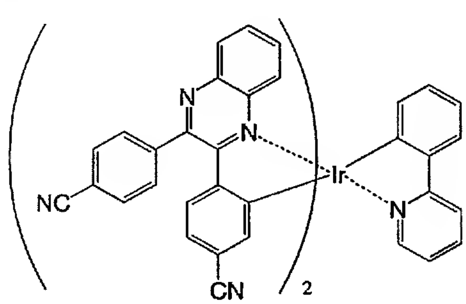


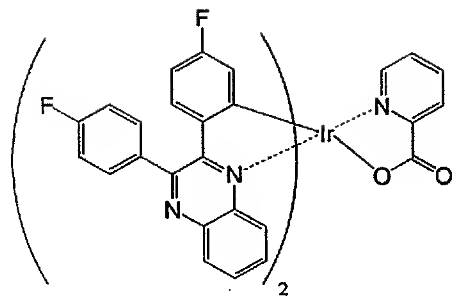
(54)

[Chemical Formula 50]



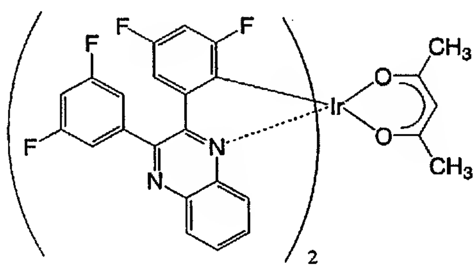
(55)

[Chemical Formula 51]



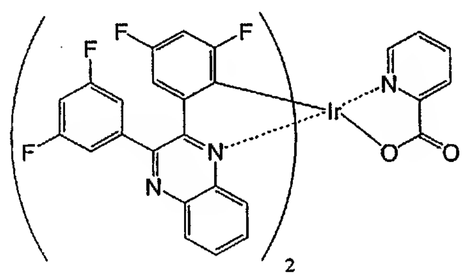
(56)

[Chemical Formula 52]



(57)

[Chemical Formula 53]



(58)

[0060]

The above-mentioned organometallic complexes according to the present invention are capable of emitting phosphorescence. In addition, the organometallic complexes according to the present invention can be applied to a light-emitting element as a luminescent material. In addition, the organometallic complexes according to the present invention can be applied to a light-emitting element as a photosensitizer.

[0061]

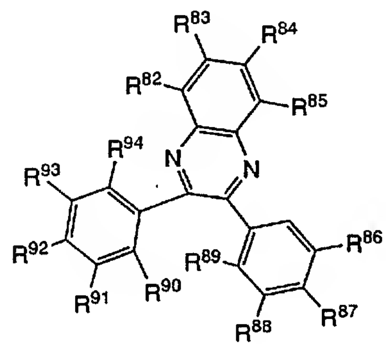
(Embodiment Mode 2)

An organometallic complex according to the present invention can be obtained by ortho metallation reaction of a ligand. For example, an organometallic complex

including a ligand represented by the following general formula (59) can be obtained by ortho metallation reaction of a ligand represented by the following general formula (59). In this embodiment mode, a method for synthesizing an organometallic complex represented by the general formula (14) with the use of a ligand represented by the general formula (59) will be described below.

[0062]

[Chemical Formula 54]



(59)

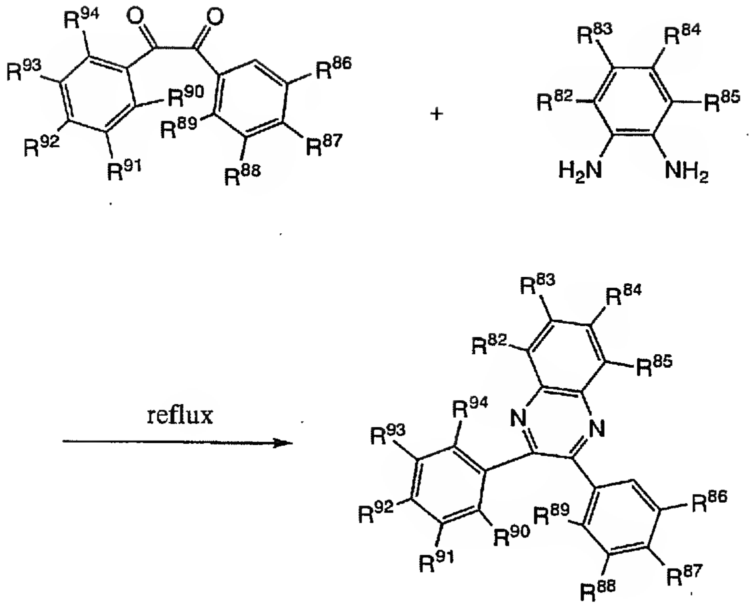
[0063]

In the formula (59), $R^{82} \sim R^{94}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent.

[0064]

It is to be noted that a ligand represented by the above general formula (59) can be synthesized, for example, as shown in the following synthesis scheme (59). In addition, another ligand in an organometallic complex used the present invention can be synthesized in a similar way.

[0065]



(60)

[0066]

In the general formula (60), $R^{82} \sim R^{94}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent.

[0067]

The thus obtained ligand represented by the general formula (59) is used to synthesize an organometallic complex according to the present invention. The following synthesis method may be used for a reaction (oratho metallation reaction) in this case.

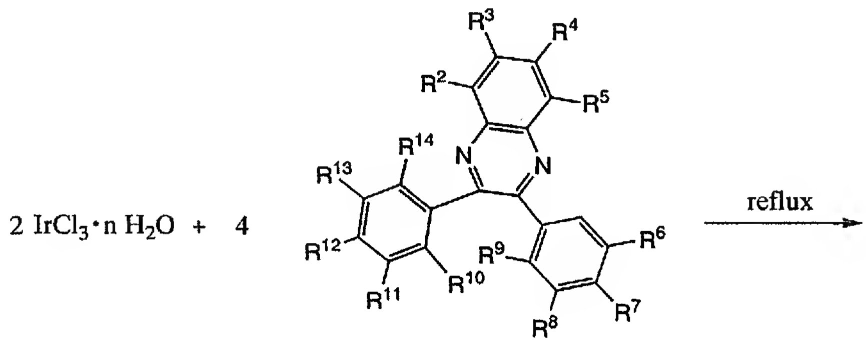
[0068]

When an organometallic complex used in the present invention is synthesized with iridium as a central metal, a chloro-bridged dinuclear complex is first synthesized with the use of iridium chloride hydrate as a raw material for the central metal by mixing the iridium chloride hydrate with the ligand represented by the general formula (59) and holding the iridium chloride hydrate mixed with the ligand at reflux in a nitrogen atmosphere (the following synthesis scheme (61)). Next, by mixing the obtained dinuclear complex with a ligand L and holding the dinuclear complex mixed with the ligand L at reflux in a nitrogen atmosphere, the chlorine bridge is cut with the

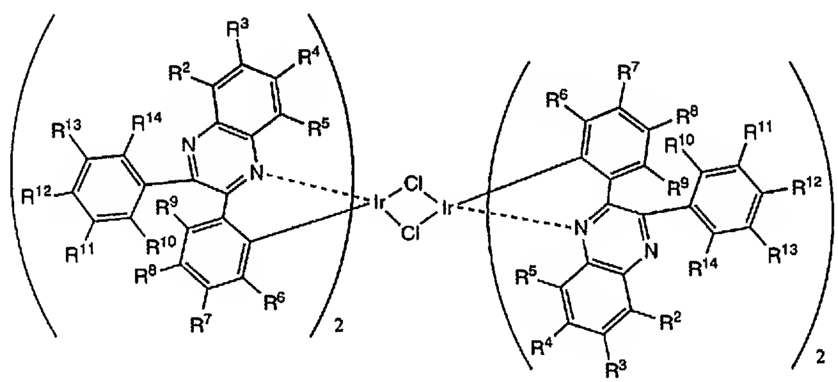
ligand L to obtain an organometallic complex used in the present invention (the following synthesis scheme (62)). There is no particular limitation on the ligand L, however, a ligand represented by any one of structural formulas (5) ~ (11) is preferable.

[0069]

[Chemical Formula 56]



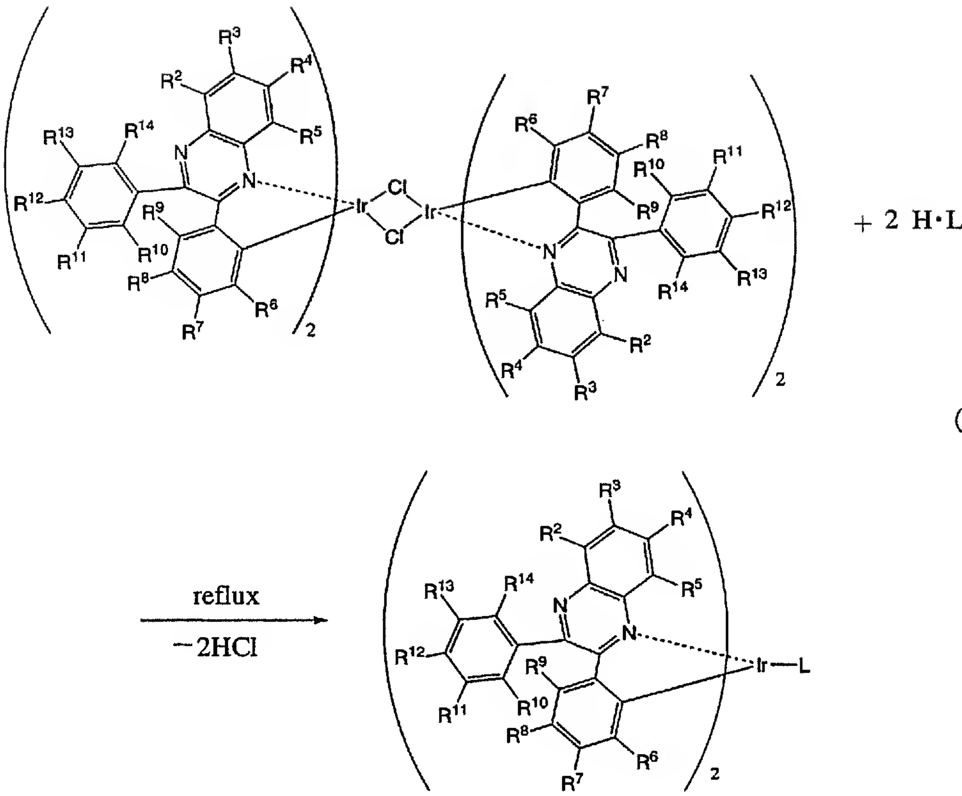
(61)



In the general formula (61), R^{82} ~ R^{94} are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent.

[0070]

[Chemical Formula 57]



(62)

In the general formula (62), $R^{82} \sim R^{94}$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, a heterocyclic group, or an electron-withdrawing substituent.

[0071]

It is to be noted that the synthesis method of an organometallic complex used in the present invention is not to be considered limited to the synthesis method described above.

[0072]

(Embodiment mode 3)

The example of a light-emitting element using an organometallic complex according to the present invention as a luminescent material will be described with reference to FIG. 1.

[0073]

In FIG. 1, a light-emitting element that has a light-emitting layer 163 between a

first electrode 151 and a second electrode 152 is shown. In the light-emitting layer 163, an organometallic complex including a structure represented by any one of general formulas (1), (2), (12) and (13) according to the present invention or an organometallic complex represented by any one of general formulas (3), (4), (14) and (15) according to the present invention is included.

[0074]

In this light-emitting element, a hole injected from the first electrode 151 and an electron injected from the second electrode 152 are recombined in the light-emitting layer 163 to bring the organometallic complex to an excited state. Then, light is emitted when the organometallic complex according to the present invention in the excited state returns to the ground state. As just described, the organometallic complex according to the present invention serves as a luminescent material. It is to be noted that the first electrode 151 and the second electrode 152 respectively serve as an anode and a cathode in the light-emitting element in the present embodiment mode.

[0075]

Here, the light-emitting layer 163 is not particularly limited. However, it is preferable that the light-emitting layer 163 be a layer in which the organometallic complex according to the present invention is included so as to be dispersed in a layer composed of a material that has a larger energy gap than the organometallic complex has. This makes it possible to prevent quenching of luminescence from the organometallic complex according to the present invention due to the concentration. It is to be noted that an energy gap indicates an energy gap between a LUMO level and a HOMO level.

[0076]

The material to be used for dispersing the organometallic complex according to the present invention is not particularly limited. However, carbazole derivatives such as 4,4'-bis(*N*-carbazolyl)-biphenyl (abbreviation: CBP) and 4,4',4''-tris(N-carbazolyl)-triphenylamine (abbreviation: TCTA) and metal complexes such as bis[2-(2'-hydroxyphenyl)-pyridinato]zinc (abbreviation: $Znpp_2$), bis[2-(2-hydroxyphenyl)-benzoxazolato]zinc (abbreviation: ZnBOX), and

tris(8-quinolinolato)aluminum (abbreviation: Alq_3) are preferable in addition to compounds having an arylamine skeleton such as 2,3-bis(4-diphenylaminophenyl)quinoxaline (abbreviation: TPAQn) and 4,4'-bis[*N*-(1-naphthyl)-*N*-phenylamino]biphenyl (abbreviation: α-NPD).

[0077]

It is to be noted that it is preferable to be a light-emitting element particularly using, among the organometallic complexes, an organometallic complex having an electron-withdrawing substituent such as a halogen group, a holoalkyl group, or a cyano group as a luminescent material. This makes it possible to obtain a light-emitting element that is excellent in chromaticity and quantum efficiency.

[0078]

In addition, a fluoro group among halogen groups and a trifluoromethyl group among holoalkyl groups are particularly preferable. By using an organometallic complex having any of these substituent as a luminescent material, a light-emitting element that is high in recombination efficiency can be obtained.

[0079]

Although the first electrode 151 is not particularly limited, it is preferable that the first electrode 151 be formed by using a material that has a larger work function when the first electrode 151 functions as an anode as in the present embodiment mode. Specifically, in addition to indium tin oxide (ITO), indium tin oxide including silicon oxide, and indium oxide including zinc oxide at 2 ~ 20 %, gold (Au), platinum (Pt), nickel (Ni), tungsten (W), chromium (Cr), molybdenum (Mo), iron (Fe), cobalt (Co), copper (Cu), palladium (Pd), and the like can be used. The first electrode 151 can be formed by, for example, sputtering or evaporation.

[0080]

In addition, although the second electrode 152 is not particularly limited, it is preferable that the second electrode 152 be formed by using a material that has a smaller work function when the second electrode 152 functions as a cathode as in the present embodiment mode. Specifically, aluminum containing an alkali metal or an alkali-earth metal such as lithium (Li) or magnesium, and the like can be used. The

second electrode 152 can be formed by, for example, sputtering or evaporation.

[0081]

Further, in order to extract emitted light to the outside, it is preferable that any one or both of the first electrode 151 and the second electrode 152 be an electrode composed of a material such as indium tin oxide or an electrode formed to be several ~ several tens nm in thickness so that visible light can be transmitted.

[0082]

In addition, a hole transporting layer 162 may be provided between the first electrode 151 and the light-emitting layer 163 as shown in FIG. 1. Here, a hole transporting layer is a layer that has a function of transporting holes injected from the first electrode 151 to the light-emitting layer 163. By providing the hole transporting layer 162 to keep the first electrode 151 away from the light-emitting layer 163 in this way, quenching of luminescence due to a metal can be prevented.

[0083]

The hole transporting layer 162 is not particularly limited, and it is possible to use a layer formed with the use of, for example, an aromatic amine compound (that is, compound including a bond of a benzene ring-nitrogen) such as 4,4'-bis[*N*-(1-naphthyl)-*N*-phenyl-amino]-biphenyl (abbreviation: α-NPD), 4,4'-bis[*N*-(3-methylphenyl)-*N*-phenyl-amino]-biphenyl (abbreviation: TPD), 4,4',4"-tris(*N*,*N*-diphenyl-amino)-triphenylamine (abbreviation: TDATA), or 4,4',4"-tris[*N*-(3-methylphenyl)-*N*-phenyl-amino]-triphenylamine (abbreviation: MTDATA).

[0084]

In addition, the hole transporting layer 162 may be a layer that has a multilayer structure formed by combining two or more layers each including the material mentioned above.

[0085]

Further, an electron transporting layer 164 may be provided between the second electrode 152 and the light-emitting layer 163 as shown in FIG. 1. Here, an electron transporting layer is a layer that has a function of transporting electrons

injected from the second electrode 152 to the light-emitting layer 163. By providing the electron transporting layer 164 to keep the second electrode 152 away from the light-emitting layer 163 in this way, quenching of luminescence due to a metal can be prevented.

[0086]

The electron transporting layer 164 is not particularly limited, and it is possible to use a layer formed with the use of, for example, a metal complex including a quinoline skeleton or a benzoquinoline skeleton such as tris(8-quinolinolato)aluminum (abbreviation: Alq_3), tris(4-methyl-8-quinolinolato)aluminum (abbreviation: $Almq_3$), bis(10-hydroxybenzo[*h*]quinolinato)beryllium (abbreviation: $BeBq_2$), or bis(2-methyl-8-quinolinolato)-4-phenylphenolato-aluminum (abbreviation: BAlq). In addition, a layer formed with the use of, for example, a metal complex including a oxazole-based ligand or a thiazole-based ligand such as bis[2-(2-hydroxyphenyl)-benzoxazolato]zinc (abbreviation: $ZnBOX_2$) or bis[2-(2-hydroxyphenyl)-benzothiazolato]zinc (abbreviation: $Zn(BTZ)_2$), may be used. Further, a layer formed with the use of 2-(4-biphenylyl)-5-(4-*tert*-butylphenyl)-1,3,4-oxadiazole (abbreviation: PBD), 1,3-bis[5-(*p*-*tert*-butylphenyl)-1,3,4-oxadiazole-2-yl]benzene (abbreviation: to as OXD-7), 3-(4-*tert*-butylphenyl)-4-phenyl-5-(4-biphenylyl)-1,2,4-triazole (abbreviation: TAZ), 3-(4-*tert*-butylphenyl)-4-(4-ethylphenyl)-5-(4-biphenylyl)-1,2,4-triazole (abbreviation: p-EtTAZ), bathophenanthroline (abbreviation: BPhen), bathocuproine (abbreviation: BCP) or the like may be used.

[0087]

In addition, the electron transporting layer 164 may be a layer that has a multilayer structure formed by combining two or more layers each including the material mentioned above.

[0088]

Further, a hole injecting layer 161 may be provided between the first electrode 151 and the hole transporting layer 162 as shown in FIG. 1. Here, a hole injecting layer is a layer that has a function of assisting injection of holes from an electrode to

serve as an anode to the hole transporting layer 162. It is to be noted that injection of holes into a light-emitting layer may be assisted by providing a hole injecting layer between an electrode to serve as an anode and the light-emitting layer when no hole transporting layer is particularly provided.

[0089]

The hole injecting layer 161 is not particularly limited, and it is possible to use a layer formed with the use of, for example, a metal oxide such as molybdenum oxide (MoOx), vanadium oxide (VOx), ruthenium oxide (RuOx), tungsten oxide (WOx), manganese oxide (MnOx). In addition, the hole injecting layer 161 can be formed with the use of a phthalocyanine compound such as phthalocyanine (abbreviation: H_2Pc) or copper phthalocyanine (abbreviation: CuPc), a poly(ethylenedioxythiophene)/poly(styrene sulfonate) aqueous solution (PEDOT/PSS), or the like.

[0090]

Further, an electron injecting layer 165 may be provided between the second electrode 152 and the electron transporting layer 164 as shown in FIG. 1. Here, an electron injecting layer is a layer that has a function of assisting injection of electrons from an electrode to serve as a cathode to the electron transporting layer 164. It is to be noted that injection of electrons into a light-emitting layer may be assisted by providing an electron injecting layer between an electrode to serve as a cathode and the light-emitting layer when no electron transporting layer is particularly provided.

[0091]

The electron injecting layer 165 is not particularly limited, it is possible to use a layer formed with the use of, for example, a compound of an alkali metal or an alkali-earth metal such as lithium fluoride (LiF), cesium fluoride (CsF), or calcium fluoride (CaF_2). In addition, a layer in which a highly electron transporting material such as Alq_3 or 4,4-bis(5-methylbenzoxazol-2-yl)stilbene (abbreviation: BzOS) is mixed with an alkali metal or an alkali-earth metal such as magnesium or lithium can also be used as the electron injecting layer 165.

[0092]

In the above-described light-emitting element according to the present invention, each of the hole injecting layer 161, the hole transporting layer 162, the light-emitting layer 163, the electron transporting layer 164, and the electron injecting layer 165 may be formed by any method, for example, evaporation, inkjet, or coating. In addition, the first electrode 151 and the second electrode 152 may be formed by any method, for example, sputtering or evaporation.

[0093]

The above-described light-emitting element according to the present invention is capable of providing red luminescence that is excellent in chromaticity since the organometallic complex according to the present invention is used. In addition, the light-emitting element according to the present invention is excellent in luminous efficiency since phosphorescence can be emitted. Further, a light-emitting element including a layer in which an organometallic complex according to the present invention is dispersed in a layer composed of a quinoxaline derivative particularly emits light efficiently.

[0094]

(Embodiment mode 4)

A light-emitting element according to the present invention may have a plurality of light-emitting layers. For example, white light can be obtained by providing a plurality of light-emitting layers and mixing luminescence from respective light-emitting layers. In the present embodiment mode, examples of a light-emitting element that has a plurality of light-emitting layers will be described with reference to FIGS. 2 and 3.

[0095]

In FIG. 2, a first light-emitting layer 763 and a second light-emitting layer 765 are provided between a first electrode 751 and a second electrode 752. It is preferable to provide a partition layer 764 between the first light-emitting layer 763 and the second light-emitting layer 765.

[0096]

When a voltage is applied so that the potential of the second electrode 752 is

higher than the potential of the first electrode 751, current flows between the first electrode 751 and the second electrode 752, and a hole and an electron are recombined in the first light-emitting layer 763, the second light-emitting layer 765, or the partition layer 764. Generated excitation energy transfers to both the first light-emitting layer 763 and the second light-emitting layer 765 through the partition layer 764, and a first luminescent material included in the first light-emitting layer 763 and a second luminescent material included in the second light-emitting layer 765 are excited. Then. Light is emitted when the excited first and second luminescent materials return to the respective ground states.

[0097]

The first light-emitting layer 763 includes a luminescent material typified by a fluorescent material such as perylene, 2,5,8,11-tetra-*tert*-butylperylene (TBP), 4,4'-bis(2,2-diphenylvinyl)biphenyl (DPVBi), 4,4'-bis[2-(*N*-ethylcarbazole-3-yl)vinyl]biphenyl (BCzVBi), bis(2-methyl-8-quinolinolato)-4-phenylphenolato-aluminum (BAlq), or bis(2-methyl-8-quinolinolato)-chlorogallium ($Gamq_2Cl$), or a phosphorescent material such as bis[2-(3,5 -bis(trifluoromethyl)phenyl)pyridinato-$N,C^{2'}$]iridium(III) picolinate ($Ir(CF_3ppy)_2(pic)$), bis[2-(4,6-difluorophenyl)pyridinato-$N,C^{2'}$]iridium(III) acetylacetonate (FIr(acac)), or bis[2-(4,6-difluorophenyl)pyridinato-$N,C^{2'}$]iridium(III) picolinate (FIr(pic)), from which luminescence with a peak at 450 ~ 510 nm in an emission spectrum can be obtained. In addition, the second light-emitting layer 765 includes an organometallic complex according to the present invention to serve as a luminescent material, and luminescence with a peak at 580 ~ 680 nm in an emission spectrum can be obtained from the second light-emitting layer 765. Then, the luminescent color of luminescence from the first light-emitting layer 763 and the luminescent color of luminescence from the second light-emitting layer 765 are emitted to the outside through one or both of the first electrode 751 and the second electrode 752. Each luminescence emitted to the outside is visually mixed to be visually recognized as white light.

[0098]

It is preferable that the first light-emitting layer 763 be a layer in which a luminescent material that is capable of providing luminescence of 450 to 510 nm is included to be dispersed in a layer composed of a material (first host) that has a larger energy gap than the luminescent material, or a layer composed of a luminescent material that is capable of providing luminescence of 450 ~ 510 nm. As the first host, in addition to α-NPD, CBP, TCTA, $Znpp_2$, and ZnBOX mentioned above, 9,10-di(2-naphthyl)anthracene (abbreviation: DNA), 9,10-di(2-naphthyl)-2-*tert*-butylanthracene (abbreviation: t-BuDNA), and the like can be used. Further, it is preferable that the second light-emitting layer 765 be a layer in which an organometallic complex according to the present invention is included to be dispersed in a layer composed of a material (second host) that has a larger energy gap than the organometallic complex according to the present invention. As the second host, TPAQn, α-NPD, CBP, TCTA, $Znpp_2$, ZnBOX, Alq_3, and the like can be used. Further, it is preferable that the partition layer 764 be formed so that energy generated in the first light-emitting layer 763, the second light-emitting layer 765, or the partition layer 764 can transfer to both the first light-emitting layer 763 and the second light-emitting layer 765, and be formed to have a function for preventing energy from transferring only one of the first light-emitting layer 763 and the second light-emitting layer 765. Specifically, the partition layer 764 can be formed with the use of TPAQn, α-NPD, CBP, TCTA, $Znpp_2$, ZnBOX, or the like. As described above, by providing the partition layer 764, it is possible to prevent a problem that stronger emission strength from only one of the first light-emitting layer 763 and the second light-emitting layer 765 makes it impossible to obtain white light.

[0099]

In the present embodiment mode, the luminescent material included in each of the first light-emitting layer 763 and the second light-emitting layer 765 is not particularly limited. However, as in the present embodiment mode, when a luminescent material with which carriers are easily trapped is included for a light-emitting layer (the second light-emitting layer 765 in the present embodiment mode) that is closer to an electrode to serve as an cathode (the second electrode 752 in

the present embodiment mode), the luminescent material included in each layer is made to emit light more efficiently.

[0100]

In addition, in the present embodiment mode, the light-emitting layer in which the two light-emitting layers are provided as shown in FIG. 2 is described. However, the number of light-emitting layer is not to be considered limited to two, and for example, three light-emitting layers may be used. Further, luminescence from each light-emitting layer may be combined to be visually recognized as white light.

[0101]

Furthermore, an electron transporting layer 762 may be provided between the first light-emitting layer 763 and the first electrode 751 as shown in FIG. 2, an electron injecting layer 761 may be provided between the electron transporting layer 762 and the first electrode 751 in addition to the electron transporting layer 762, a hole transporting layer 766 may be provided between the second light-emitting layer 765 and the second electrode 752 as shown in FIG. 2, and a hole injecting layer 767 may be provided between the hole transporting layer 766 and the second electrode 752.

[0102]

In addition to the light-emitting element described with reference to FIG, 2, a light-emitting element shown in FIG. 3 may be used.

[0103]

The light-emitting element shown in FIG. 3 has a first light-emitting layer 783 and a second light-emitting layer 788 between a first electrode 771 and a second electrode 772. Between the first light-emitting layer 783 and the second light-emitting layer 788, a first layer 785 and a second layer 786 are provided.

[0104]

The first layer 785 is a layer that generates holes, and the second layer 786 is a layer that generates electrons. When a voltage is applied so that the potential of the second electrode 772 is higher than the potential of the first electrode 771, an electron injected from the first electrode 771 and a hole injected from the first layer 785 are recombined in the first light-emitting layer 783, and a luminescent material included in

the first light-emitting layer 783 emits light. Further, a hole injected from the second electrode and an electron injected from the second layer 786 are recombined in the second light-emitting layer 788, and a luminescent material included in the second light-emitting layer 788 emits light.

[0105]

In the first light-emitting layer 783, an organometallic complex according to the present invention is included so as to serve as a luminescent material, and luminescence with a peak at 580 ~ 680 nm in an emission spectrum can be obtained from the first light-emitting layer 783. In addition, the second light-emitting layer 788 includes a luminescent material typified by a fluorescent material such as perylene, TBP, DPVBi, BCzVBi, BAlq, or $Gamq_2Cl$, or a phosphorescent material such as $Ir(CF_3ppy)_2(pic)$, FIr(acac), or FIr(pic), from which luminescence with a peak at 450 ~ 510 nm in an emission spectrum can be obtained. Luminescence from the first light-emitting layer 783 and the second light-emitting layer 788 is emitted from one or both of the first electrode 771 and the second electrode 772. Then, the luminescence from each light-emitting layer is visually mixed to be visually recognized as white light.

[0106]

In the first light-emitting layer 783, it is preferable that the organometallic complex according the present invention be included to be dispersed in the second host as described above. It is also preferable that the second light-emitting layer 788 be formed in the same way as the second light-emitting layer 788 described above.

[0107]

It is preferable that the first layer 785 be a layer in which a highly hole transporting material rather than an electron transporting material includes a material that shows an electron-accepting property to the highly hole transporting material. As the highly hole transporting material, the same material as a material that is used for forming a hole transporting layer may be used. In addition, as the material that shows an electron-accepting property to the highly hole transporting material, molybdenum oxide, vanadium oxide, 7,7,8,8-tetracyanoquinodimethane (abbreviation: TCNQ), 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (abbreviation: F4-TCQN), and the

like can be used.

[0108]

It is preferable that the second layer 786 be a layer in which a highly electron transporting material rather than a hole transporting material includes a material that shows an electron-donating property to the highly electron transporting material. As the highly electron transporting material, the same material as a material that is used for forming an electron transporting layer may be used. In addition, as the material that shows an electron-donating property to the highly electron transporting material, alkali metals such as lithium and cesium, alkali-earth metals such as magnesium and calcium, rare-earth metals such as erbium and ytterbium, and the like can be used.

[0109]

Furthermore, an electron transporting layer 782 may be provided between the first light-emitting layer 783 and the first electrode 771 as shown in FIG. 3, an electron injecting layer 781 may be provided between the electron transporting layer 782 and the first electrode 771, a hole transporting layer 784 may be provided between the first light-emitting layer 783 and the first layer 785, a hole transporting layer 789 may be provided between the second light-emitting layer 788 and the second electrode 772, a hole injecting layer 790 may be provided between the hole transporting layer 789 and the second electrode 772, and an electron transporting layer 787 may be provided between the second light-emitting layer 788 and the second layer 786 .

[0110]

In addition, in the present embodiment mode, the light-emitting element in which the two light-emitting layers are provided as shown in FIG. 3 is described. However, the number of the light-emitting layer is not to be considered limited to two, and for example, three light-emitting layers may be used. Further, luminescence from each light-emitting layer may be combined to be visually recognized as white light.

[0111]

(Embodiment mode 5)

The example of a light-emitting element using an organometallic complex according to the present invention as a sensitizer will be described with reference to FIG.

4.

[0112]

FIG. 4 shows a light-emitting element that has a light-emitting layer 193 between a first electrode 181 and a second electrode 182. The light-emitting layer 193 includes an organometallic complex including a structure represented by any one of the general formulas (1), (2), (12) and (13) according to the present invention or an organometallic complex represented by any one of the general formulas (3), (4), (14) and (15) according to the present invention, and a fluorescent compound that is capable of providing luminescence of a longer wavelength than organometallic complex according to the present invention. Here, a fluorescent compound is a substance which emits light while returning from an excited state to a ground state.

[0113]

In this light-emitting element, a hole injected from the first electrode 181 and an electron injected from the second electrode 182 are recombined in the light-emitting layer 193 to bring the fluorescent compound into an excited state. Then, light is emitted when the fluorescent compound in the excited state returns to the ground state. In this case, the organometallic complex acts as a sensitizer for the fluorescent compound to increase the number of singlet excited states of the fluorescent compound. As described above, a light-emitting element that is excellent in luminous efficiency can be obtained by using an organometallic complex according to the present invention as a sensitizer. It is to be noted that the first electrode 181 and the second electrode 182 respectively serve as an anode and a cathode in the light-emitting element in the present embodiment mode.

[0114]

Here, the light-emitting layer 193 is not particularly limited. However, it is preferable that the light-emitting layer 193 be a layer in which the organometallic complex according to the present invention and the fluorescent compound are included so as to be dispersed in a layer composed of a material that has a larger energy gap than the organometallic complex has. This makes it possible to prevent quenching of luminescence from the organometallic complex according to the present invention due

to the concentration. It is to be noted that an energy gap indicates an energy gap between a LUMO level and a HOMO level.

[0115]

Here, although the fluorescent compound is not particularly limited, compounds that show red ~ infrared luminescence such as magnesium phthalocyanine and phthalocyanine are preferable.

[0116]

In addition, the material to be used for dispersing the organometallic complex according to the present invention and the fluorescent compound is not particularly limited, and the materials that can be used for dispersing the organometallic complex according to the present invention, which are described in Embodiment mode 3, and the like can be used.

[0117]

In addition, the first electrode or the second electrode is not particularly limited, and the same materials as those for the first electrode 181 and second electrode 182 described in Embodiment mode 3, can be used.

[0118]

Furthermore, a hole transporting layer 191, a hole injecting layer 192, and the like may be provided between the first electrode 181 and the light-emitting layer 193 as shown in FIG. 4, and an electron transporting layer 194, an electron injecting layer 195, and the like may be provided also between the second electrode 182 and the light-emitting layer 193.

[0119]

For the hole transporting layer 191, the hole injecting layer 192, the electron transporting layer 194, and the electron injecting layer 195, the same materials as those for the hole transporting layer 162, the hole injecting layer 161, the electron transporting layer 164, and the electron injecting layer 165 described in Embodiment mode 3, can be used, respectively. In addition, another functional layer that has a different function from the hole transporting layer 191, the hole injecting layer 192, the electron transporting layer 194, and the electron injecting layer 195 may be provided.

[0120]

The light-emitting element described above can be obtained by using an organometallic complex according to the present invention as a sensitizer.

[0121]

(Embodiment mode 6)

Since a light-emitting element including an organometallic complex according to the present invention shows a favorable luminescent color, a light-emitting device that has a function of displaying favorable images in terms of color can be obtained by using the light-emitting element according to the present invention for a pixel. Further, since the light-emitting element according to the present invention is capable of emitting light efficiently, a light-emitting device with low power consumption can be obtained by using the light-emitting element according to the present invention for a pixel or the like.

[0122]

In the present embodiment mode, a circuit configuration and driving method of a light-emitting device that has a display function will be described with reference to FIGS. 5 ~ 8.

[0123]

FIG. 5 is an overhead schematic view of a light-emitting device to which the present invention is applied. In FIG. 5, a pixel portion 6511, a source signal line driver circuit 6512, a writing gate signal line driver circuit 6513, and an erasing gate signal line driver circuit 6514 are provided on a substrate 6500. Each of the source signal line driver circuit 6512, the writing gate signal line driver circuit 6513, and the erasing gate signal line driver circuit 6514 is connected to FPC (Flexible Printed Circuit) 6503 that is an external input terminal through a group of wirings. Further, each of the source signal line driver circuit 6512, the writing gate signal line driver circuit 6513, and the erasing gate signal line driver circuit 6514 receives signals such as a clock signal, a start signal, and a reset signal from the FPC 6503. In addition, a printed wiring board (PWB) 6504 is attached to the FPC 6503. It is to be noted that it is not always necessary to provide the driver circuit portion on the same substrate on which

the pixel portion 6511 is provided as described above. For example, the driver circuit portion may be provided outside the substrate by using a TCP that has an IC chip on an FPC on which a wiring pattern is formed.

[0124]

In the pixel portion 6511, a plurality of source signal lines extending in columns is arranged in rows, current supply lines are arranged to line in rows, and a plurality of gate signal lines extending in rows is arranged to line in columns. Further, in the pixel portion 6511, a plurality of circuits each including a light-emitting element is arranged.

[0125]

FIG. 6 is a diagram showing a circuit for operating one pixel. The circuit shown in FIG. 6 includes a first transistor 901, a second transistor 902, and a light-emitting element 903.

[0126]

Each of the first transistor 901 and the second transistor 902 is a three-terminal element including a gate electrode, a drain region, and a source region, and including a channel region between the drain region and the source region. Here, since a source region and a drain region are switched with each other in accordance with a structure or operating conditions of a transistor, it is difficult to identify which one is the drain region or the source region. Consequently, regions that serve as a source or a drain are referred to as first and second electrodes in the present embodiment mode.

[0127]

A gate signal line 911 and a writing gate signal line driver circuit 913 are provided so as to be electrically connected or unconnected by a switch 918, the gate signal line 911 and an erasing gate signal line driver circuit 914 are provided so as to be electrically connected or unconnected by a switch 919, and a source signal line 912 is provided so as to be electrically connected to any one of a source signal line driver circuit 915 and a power source 916 by a switch 920. Further, the first transistor 901 has a gate electrically connected to the gate signal line 911, a first electrode electrically connected to the source signal line 912, and a second electrode electrically connected to

a gate electrode of the second transistor 902. The second transistor 902 has a first electrode electrically connected to a current supply line 917 and a second electrode electrically connected to one electrode included in the light-emitting element 903. It is to be noted that the switch 918 may be included in the writing gate signal line driver circuit 913, the switch 919 may be included in the erasing gate signal line driver circuit 914, and the switch 920 may be included in the source signal line driver circuit 915.

[0128]

In addition, arrangement of a transistor, a light-emitting element, and the like in a pixel portion is not particularly limited. For example, arrangement shown in a top view of FIG. 7 can be employed. In FIG. 7, a first transistor 1001 has a first electrode connected to a source signal line 1004 and a second electrode connected to a gate electrode of a second transistor 1002. Further, the second transistor has a first electrode connected to a current supply line 1005 and a second electrode connected an electrode 1006 of a light-emitting element. A portion of a gate signal line 1003 serves as a gate electrode of the first transistor 1001.

[0129]

Next, a driving method will be described. FIG. 8 is a diagram illustrating operation per frame with time. In FIG. 8, the lateral direction indicates passage of time, and the vertical direction indicates the number of scanning stages of gate signal lines.

[0130]

When a light-emitting device according to the present invention is used to display images, rewrite operation and image display operation for a screen are repeated in a display period. Although the number of rewrites is not particularly limited, it is preferable that the number of rewrites be about 60 times per second so as not to make an image viewer recognize flickers. Here, a period for which rewrite operation and display operation are performed for a screen (one frame) is referred to as one frame period.

[0131]

As shown in FIG. 8, one frame is divided into four sub-frames 501, 502, 503, and 504 respectively including writing periods 501a, 502a, 503a, and 504a and retention

periods 501b, 502b, 503b, and 504b. In the retention period, a light-emitting element to which a signal for emitting light is given is made to be in an emitting state. The ratio of the length of the retention period in each sub-frame is first sub-frame 501 : second sub-frame 502 : third sub-frame 503 : fourth sub-frame 504 = $2^3 : 2^2 : 2^1 : 2^0$ = 8 : 4 : 2 : 1. This makes 4-bit gradation possible. However, the number of bits or the number of gradations is not limited to that described here. For example, eight sub-frames may be provided so as to perform 8-bit gradation.

[0132]

Operation in one frame will be described. First, in the sub-frame 501, writing operation is sequentially performed for each of the first row to the last row. Accordingly, the start time of the writing period is different depending on the row. When the writing period 501a is completed, the row is sequentially moved into the retention period 501b. In the retention period 501b, a light-emitting element to which a signal for emitting light is given is made to be in an emitting state. Further, when the retention period 501b is completed, the row is sequentially moved into the next sub-frame 502, and writing operation is sequentially performed for each of the first row to the last row as in the case of the sub-frame 501. The operation described above is repeated to complete the retention period 504b of the sub-frame 504. When the operation in the sub-frame 504 is completed, the row is moved into the next frame. Thus, the total of time for which light is emitted in each sub-frame is emission time for each light-emitting element in one frame. By varying this emission time with respect to each light-emitting element to have various combinations in one pixel, various different display colors in luminosity and chromaticity can be made.

[0133]

As in the sub-frame 504, when forcible termination of a retention period of a row for which writing is already completed to move into the retention time is required before writing for the last row is completed, it is preferable that an erasing period 504c be provided after the retention period 504b and a row be controlled so as to be in a non-emitting state forcibly. Further, the row made to be in the non-emitting state forcibly is kept the non-emitting state for a certain period (this period is referred to as a

non-emission period 504d). Then, immediately after the writing period of the last row is completed, the rows are sequentially moved into the next writing period (or the next frame), starting from the first row. This makes it possible to prevent the writing period of the sub-frame 504 from overlapping with the writing period of the next sub-frame.

[0134]

Although the sub-frames 501 to 504 are arranged in the order of retention period from longest to shortest in the present embodiment mode, the arrangement as in the present embodiment mode is not always necessary. For example, the sub-frames 501 to 504 may be arranged in the order of retention period from shortest to longest, or may be arranged in random order. In addition, the sub-frames may be divided further into a plurality of frames. Namely, scanning of the gate signal lines may be performed more than once while giving the same image signal.

[0135]

Now, operation of the circuit shown in FIG. 6 in a writing period and an erasing period will be described.

[0136]

First, operation in a writing period will be described. In the writing period, the n-th (n is a natural number) gate signal line 911 is electrically connected to the writing gate signal line driver circuit 913 through the switch 918, and unconnected to the erasing gate signal line driver circuit 914. In addition, the source signal line 912 is electrically connected to the source signal line driver circuit through the switch 920. In this case, a signal is input to the gate of the first transistor 901 connected to the n-th (n is a natural number) gate signal line 911 to turn on the first transistor 901. Then, at this moment, image signals are input simultaneously to the first to last source signal lines. It is to be noted that the image signals input from the respective source signal line 912 are independent of each other. The image signal input from the source signal lines 912 is input to the gate electrode of the second transistor 902 through the first transistor 901 connected to the each source signal line. At this time, the value of the current supplied to the light-emitting element 903 from the current supply line 917 is decided by the signals input in the second transistor 902. Then, whether the

light-emitting element 903 emits light or not is determined depending on the value of the current. For example, when the second transistor 902 is a p-channel transistor, the light-emitting element 903 is made to emit light by inputting a Low Level signal to the gate electrode of the second transistor 902. On the other hand, when the second transistor 902 is an n-channel transistor, the light-emitting element 903 is made to emit light by inputting a High Level signal to the gate electrode of the second transistor 902.

[0137]

Next, operation in an erasing period will be described. In the erasing period, the n-th (n is a natural number) gate signal line 911 is electrically connected to the erasing gate signal line driver circuit 914 through the switch 919 and unconnected to the wiring gate signal line driver circuit 913. In addition, the source signal line 912 is electrically connected to the power source 916 through the switch 920. In this case, a signal is input to the gate of the first transistor 901 connected to the n-th (n is a natural number) gate signal line 911 to turn on the first transistor 901. Then, at this moment, erasing signals are input simultaneously to the first to last source signal lines. The erasing signal input from the source signal lines 912 is input to the gate electrode of the second transistor 902 through the first transistor 901 connected to the each source signal line. At this moment, current supply from the current supply line 917 to the light-emitting element 903 is blocked in accordance with the signal input to the second transistor 902. Then, the light-emitting element 903 is forcibly made to be in a non-emitting state. For example, when the second transistor 902 is a p-channel transistor, the light-emitting element 903 is made to emit no light by inputting a High Level signal to the gate electrode of the second transistor 902. On the other hand, when the second transistor 902 is an n-channel transistor, the light-emitting element 903 is made to emit no light by inputting a Low Level signal to the gate electrode of the second transistor 902.

[0138]

It is to be noted that, as for the n-th row (n is a natural number), signals for erasing are input by the operation as described above in an erasing period. However, as described above, the other row (referred to as the m-th row (m is a natural number))

may be in a writing period while the n-th row is in an erasing period. In such a case, it is necessary to input a signal for erasing to the n-th row and input a signal for writing to the m-th row by using the same source signal line. Therefore, operation described below is preferable.

[0139]

Immediately after the n-th light-emitting element 903 is made to emit no light by the operation in the erasing period described above, the gate signal line and the erasing gate signal line driver circuit 914 are made to be unconnected to each other, and the switch 918 is switched to connect the source signal line and the source signal line driver circuit 915. Then, in addition to connecting the source signal line to the source signal line driver circuit 915, the gate signal line is connected to the writing gate signal line driver circuit 913. Then, a signal is input selectively to the m-th gate signal line from the writing gate signal line driver circuit 913 to turn on the first transistor, and signals for writing are input to the first to last source signal lines from the source signal line driver circuit 915. This signal makes the m-th light-emitting element is made to be in an emitting or non-emitting state.

[0140]

Immediately after the writing period for the m-th row is completed as described above, an erasing period for the (n+1)-th row is started. For that purpose, the gate signal line and the writing gate signal line driver circuit 913 are made to be unconnected to each other, and the switch 918 is switched to connect the source signal line and the power source 916. Further, the gate signal line, which is unconnected to the writing gate signal line driver circuit 913, is made to be connected to the erasing gate signal line driver circuit 914. Then, a signal is input selectively to the (n+1)-th gate signal line from the erasing gate signal line driver circuit 914 to turn on the first transistor, and an erasing signal is input from the power source 916. Immediately after the erasing period for the (n+1)-th row is completed, a writing period for the (m+1)-th row is started. Then, an erasing period and a writing period may be repeated in the same way until an erasing period for the last row is completed.

[0141]

Although the example in which the writing period for the m-th row is provided between the erasing period for the n-th row and the erasing period for the (n+1)-th row is described in the present embodiment mode, the present invention is not limited to this. The writing period for the m-th row may be provided between an erasing period for (n-1)-th row and an erasing period for n-th row.

[0142]

In addition, in the present embodiment mode, the operation in which the erasing gate signal line driver circuit 914 and one gate signal line are made to be unconnected to each other and the writing gate signal line driver circuit 913 and the other gate signal line are made to be connected to each other is repeated as the non-emission period 504d is provided in the sub-frame 504. This type of operation may be performed in a frame in which a non-emission period is not particularly provided.

[0143]

(Embodiment mode 7)

One example of cross sections of a light-emitting device including a light-emitting element according to the present invention will be described with reference to FIGS. 9.

[0144]

In each of FIGS. 9, a portion surrounded by a dotted line is a transistor 11 provided for driving a light-emitting element 12 according to the present invention. The light-emitting element 12 is a light-emitting element according to the present invention, which has a layer 15 in which a hole generation layer, an electron generation layer, and a layer including a luminescent material are stacked between a first electrode 13 and a second electrode 14. The first electrode 13 and a drain of the transistor 11 are electrically connected to each other by a wiring 17 running through a first interlayer insulating film 16 (16a, 16b and 16c). In addition, the light-emitting element 12 is separated by a partition layer 18 from another light-emitting element provided adjacently. A light-emitting device that has this structure according to the present invention is provided over substrate 10.

[0145]

It is to be noted that the transistor 11 shown in each of FIGS. 9 is a top-gate TFT in which a gate electrode is provided on the opposite side of a semiconductor layer as a center from a substrate. However, the structure of the transistor 11 is not particularly limited. For example, a bottom-gate TFT may be used. In the case of a bottom-gate TFT, a TFT where a protective film is formed on a semiconductor layer that forms a channel (a channel-protection TFT) may be used, or a TFT where a portion of a semiconductor layer that forms a channel is concave (a channel-etch TFT) may be used. It is to be noted that reference numeral 21 denotes a gate electrode; 22, a gate insulating film; 23, a semiconductor layer; 24, an n-type semiconductor layer; 25, an electrode; and 26, a protective film.

[0146]

In addition, a semiconductor layer forming the transistor 11 may be either crystalline or amorphous, or alternatively, may be semi-amorphous.

[0147]

The following will describe a semi-amorphous semiconductor. The semi-amorphous semiconductor is a semiconductor that has an intermediate structure between amorphous and crystalline (such as single-crystal or polycrystalline) structures and has a third state that is stable in terms of free energy, which includes a crystalline region that has short range order and lattice distortion. Further, a crystal grain from 0.5 ~ 20 nm is included in at least a region in a film of the semi-amorphous semiconductor. A raman spectrum of the semi-amorphous semiconductor has a shift to a lower wavenumber side than 520 cm^{-1}. In X-ray diffraction, diffraction peaks of (111) and (220) due to a Si crystal lattice are observed. Hydrogen or halogen is included at 1 atomic% or more in the semi-amorphous semiconductor as a neutralizing agent for dangling bonds. Therefore, the semi-amorphous semiconductor is also referred to as a micro-crystalline semiconductor. A nitride gas is decomposed by glow discharge (plasma CVD) to form the semi-amorphous semiconductor. As the nitride gas, in addition to SiH_4, a gas such as Si_2H_6, SiH_2Cl_2, $SiHCl_3$, $SiCl_4$, or SiF_4 can be used. This nitride gas may be diluted with H_2 or with H_2 and one kind or plural kinds of rare

gas elements selected from He, Ar, Kr, and Ne, where the dilution ratio is in the range of 2 : 1 ~ 1000 : 1. The pressure during glow discharge is approximately in the range of 0.1 Pa ~ 133 Pa, and the power supply frequency is in the range of 1 MHz ~ 120 MHz, preferably 13 MHz ~ 60 MHz. The substrate heating temperature may be 300°C or less, preferably 100 ~ 250°C. It is desirable to control an impurity of an atmospheric constituent such as oxygen, nitrogen, or carbon to have a concentration of 1×10^{20} /cm^3 or less as an impurity element in the film, in particular, the oxygen concentration is controlled to be 5×10^{19} /cm^3 or less, preferably 1×10^{19} /cm^3 or less. Further, a TFT (thin film transistor) using the semi-amorphous semiconductor has a mobility of approximately 1 ~ 10 m^2/Vsec.

[0148]

Further, as a specific example of the crystalline semiconductor layer, a layer formed of single-crystal or polycrystalline silicon, silicon germanium, or the like can be given. It may be formed by laser crystallization or may be formed by crystallization with solid-phase growth method using an element such as nickel.

[0149]

In the case of using an amorphous material, for example, amorphous silicon to form the semiconductor layer, it is preferable that the light-emitting device have a circuit in which the transistor 11 and the other transistor (a transistor forming the circuit for driving the light-emitting element) are all n-channel transistors. Other than that case, the light-emitting device may have a circuit including one of an n-channel transistor and a p-channel transistor or may have a circuit including both an n-channel transistor and a p-channel transistor.

[0150]

Further, the first interlayer insulating film 16 may be a multilayer as shown in FIGS. 9(A) and 9(C), or may be a single layer. Note that 16a is made with an inorganic material such as silicon oxide or silicon nitride, and reference numeral 16b is made from a material with self-flatness such as acrylic, siloxane (a material having a skeleton structure formed by the bond of silicon (Si) and oxygen (O), and including at least hydrogen as a substituent), or silicon oxide that can be used in coating deposition.

In addition, reference numeral 16c is made with a silicon nitride film including argon (Ar). The materials included in the respective layers are not particularly limited, and therefore materials other than the materials mentioned here may be used. Further, a layer including a material other than these materials may be combined. In this way, both of an inorganic material and an organic material, or one of an inorganic material and an organic material may be used to form the first interlayer insulating film 16.

[0151]

As for the partition layer 18, it is preferable that an edge portion have a shape varying continuously in curvature radius. In addition, a material such as acrylic, siloxane, resist, or silicon oxide is used to form the partition layer 18. One or both of an inorganic material and an organic material may be used to form the partition layer 18.

[0152]

In FIGS. 9(A) and 9(C), only the first interlayer insulating film 16 is provided between the transistor 11 and the light-emitting element 12. However, as shown in FIG. 9(B), a second interlayer insulating film 19 (19a and 19b) may be provided in addition to the first interlayer insulating film 16 (16a and 16b). In the light-emitting device shown in FIG. 9(B), the first electrode 13 is connected to the wiring 17 through the second interlayer insulating film 19.

[0153]

The second interlayer insulating film 19 may be a multilayer or a single layer in the same way as the first interlayer insulating film 16. Reference numeral 19a is made from a material with self-flatness such as acrylic, siloxane (a material having a skeleton structure formed by the bond of silicon (Si) and oxygen (O), and including at least hydrogen as a substituent), or silicon oxide that can be used in coating deposition. In addition, reference numeral 19b has a silicon nitride film including argon (Ar). The materials included in the respective layers are not particularly limited, and therefore materials other than the materials mentioned here may be used. Further, a layer including a material other than these materials may be combined. In this way, both of an inorganic material and an organic material, or one of an inorganic material and an

organic material may be used to form the second interlayer insulating film 19.

[0154]

In the light-emitting element 12, in the case where both the first electrode and the second electrode are formed by using a light-transmitting material, emitted light can be extracted from both the first electrode 13 side and the second electrode 14 side as indicated by outline arrows of FIG. 9(A). In the case where only the second electrode 14 is formed by using a light-transmitting material, emitted light can be extracted from only the second electrode 14 side as indicated by an outline arrow of FIG. 9(B). In this case, it is preferable that the first electrode 13 include a highly reflective material or that a film composed of a highly reflective material (a reflective film) be provided below the first electrode 13. In the case where only the first electrode 13 is formed by using a light-transmitting material, emitted light can be extracted from only the first electrode 13 side as indicated by an outline arrow of FIG. 9(C). In this case, it is preferable that the second electrode 14 include a highly reflective material or that a reflective film be provided above the second electrode 14.

[0155]

In addition, the layer 15 may be stacked so that the light-emitting element 12 operates when a voltage is applied so that the potential of the second electrode 14 is higher than the potential of the first electrode 13, or the layer 15 may be stacked so that the light-emitting element 12 operates when a voltage is applied so that the potential of the second electrode 14 is lower than the potential of the first electrode 13. The transistor 11 is an n-channel transistor in the former case, and the transistor 11 is a p-channel transistor in the latter case.

[0156]

As described above, an active light-emitting device in which driving of a light-emitting element is controlled by a transistor is described in the present embodiment mode. However, in addition, the present invention may be applied to a passive light-emitting device in which a light-emitting element is driven without providing an element for driving such as a transistor. Also in the case of a passive light-emitting device, driving with low power consumption is possible when the passive

light-emitting device includes a light-emitting element according to the present invention, which operates at a lower driving voltage.

[0157]

Hereinafter, the present invention will be described in more detail based on the embodiment mode. However, as a matter of course, the present invention is not limited to these embodiments. First, synthesis examples of organometallic complexes for light-emitting elements according to the present invention will be described, and then, the structures of light-emitting elements according to the present invention and manufacturing method thereof, and an example of a light-emitting device will be described.

[0158]

(Embodiment mode 8)

Since a light-emitting device including a light-emitting element of the present invention can display favorable images, electronic devices which can provide superior pictures can be obtained by applying the light-emitting device of the present invention to display portions of the electronic devices. Moreover, since the light-emitting device including the light-emitting element of the present invention driven with low power consumption, electronic devices with low power consumption can be obtained by applying the light-emitting device of the present invention to the display portions of the electronic devices. For example, telephones with long battery standby time and the like can be obtained.

[0159]

In FIGS. 10, one example of an electronic device mounted with a light-emitting device applied with the present invention is shown.

[0160]

FIG. 10(A) is a laptop personal computer manufactured by applying the present invention, which includes a main body 5521, a housing 5522, a display portion 5523, a keyboard 5524, and the like. The personal computer can be completed by incorporating the light-emitting device having a light-emitting element of the present invention therein as the display portion.

[0161]

FIG. 10(B) is a telephone set manufactured by applying the present invention, which includes a main body 5552, a display portion 5551, an audio output portion 5554, an audio input portion 5555, operation switches 5556 and 5557, an antenna 5553, and the like. The telephone set can be completed by incorporating the light-emitting device having a light-emitting element of the present invention therein as the display portion.

[0162]

FIG. 10(C) is a television receiver manufactured by applying the present invention, which includes a display portion 5531, a housing 5532, speakers 5533, and the like. The television receiver can be completed by incorporating the light-emitting device having a light-emitting element of the present invention therein as the display portion.

[0163]

As described above, the light-emitting device of the present invention are extremely suitable for the display portions of various kinds of electronic devices.

[0164]

Although a personal computer is explained in this embodiment, the light-emitting device having a light-emitting element according to the present invention may be mounted in a telephone, a navigation device, a camera, or the like.

[Embodiment 1]

[0165]

Hereinafter, a synthesis example of an organometallic complex according to the present invention is explained. Note that the present invention is not limited to the organometallic complex of the following synthesis example.

[0166]

«Synthesis Example 1»

The present synthesis example is a synthesis example of bis[2,3-bis(4-fluorophenyl)quinoxalinato]iridium(III) acetylacetonate (abbreviation: $Ir(Fdpq)_2(acac)$) represented by the formula (16).

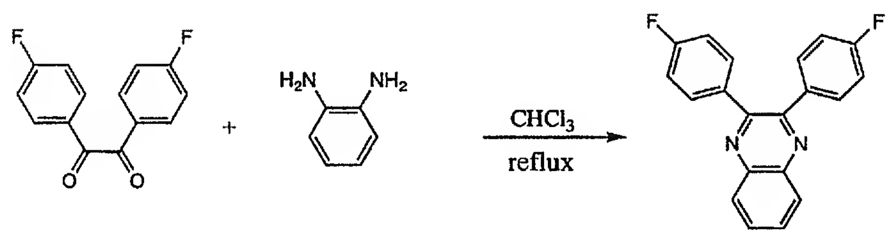
[0167]

<Step 1: Synthesis of Ligand (HFdpq)>

First, 3.71 g of 4,4'-difluorobenzil and 1.71 g of o-phenylenediamine were stirred on heating in a solvent (200 mL of chloroform) for 6 hours. The reaction solution was cooled to room temperature, washed with 1N HCl and a saturated aqueous solution of sodium chloride, and dried with magnesium sulfate. The solvent was removed to obtain a ligand HFdpq (2,3-bis(4-fluorophenyl)quinoxaline) (pale yellow powder, yield: 99 %). The synthesis scheme and the structure formula of the ligand HFdpq are shown by the following formula (63).

[0168]

[Chemical Formula 58]



(63)

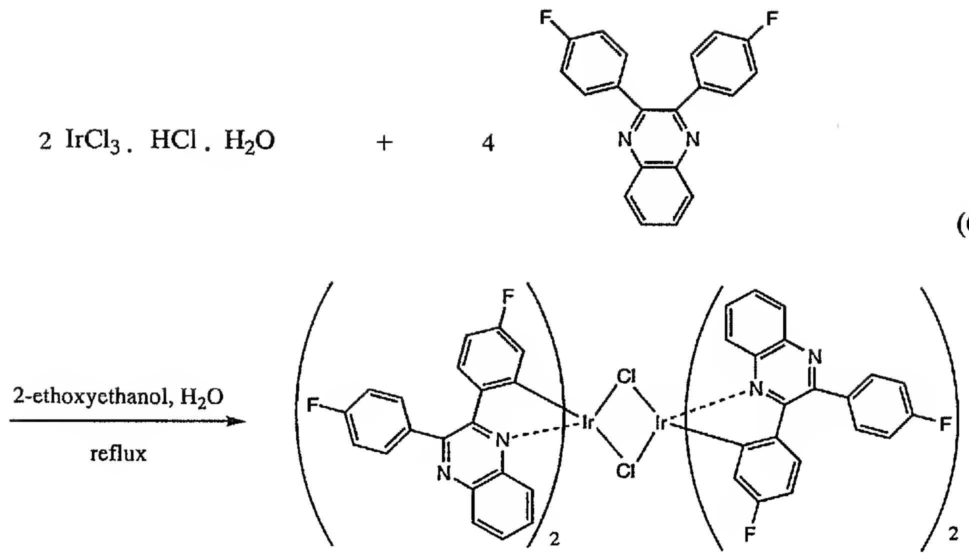
[0169]

<Step 2: Synthesis of Dinuclear Complex $[Ir(Fdpq)_2Cl]_2$>

With a mixture of 30 ml of 2 - ethoxyethanol and 10 ml of water as a solvent, 3.61 g of the ligand HFdpq (2,3-bis(4-fluorophenyl)quinoxaline) and 1.35 g of iridium chloride ($IrCl_3 \cdot HCl \cdot H_2O$) were mixed, and held at reflux in a nitrogen atmosphere for 17 hours to obtain a dinuclear complex $[Ir(Fdpq)_2Cl]_2$ (brown powder, yield: 99 %). The synthesis scheme and the structure formula of the dinuclear complex $[Ir(Fdpq)_2Cl]_2$ are shown by the following formula (64).

[0170]

[Chemical Formula 59]



(64)

[0171]

<Step 3: Synthesis of Organometallic Complex $Ir(Fdpq)_2(acac)$ used for Light-Emitting Element of the Present Invention>

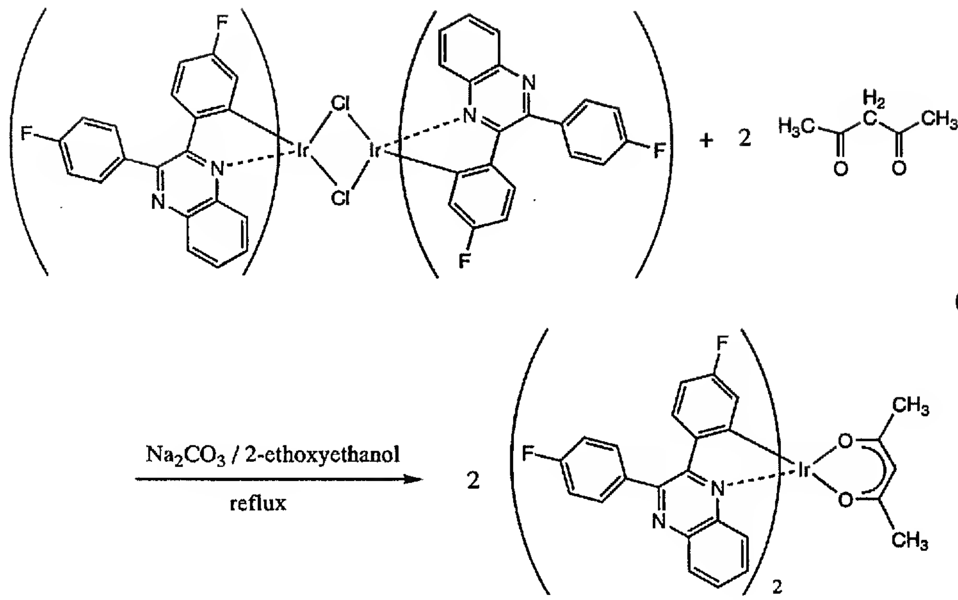
Further, with 30 ml of 2-ethoxyethanol as a solvent, 2.00 g of the dinuclear complex $[Ir(Fdpq)_2Cl]_2$ obtained in Step 2 described above, 0.44 ml of acetylacetone (Hacac), and 1.23 g of sodium carbonate were mixed, and held at reflux in a nitrogen atmosphere for 20 hours to obtain an organometallic complex $Ir(Fdpq)_2(acac)$ represented by the formula (20) according to the present invention (red powder, yield: 44 %). The synthesis scheme is shown by the following formula (65). The result of analysis of the organometallic complex $Ir(Fdpq)_2(acac)$ by nuclear magnetic resonance (^1H-NMR) is as follows.

[0172]

^1H-NMR. δ ($CDCl_3$): 8.20 (d, 2H), 8.11 (d, 2H), 8.01 (brs, 4H), 7.68 (t, 2H), 7.52 (t, 2H), 7.32 (brm, 4H), 7.08 (m, 2H), 6.39 (td, 2H), 6.05 (dd, 2H), 4.71 (s, 1H), 1.62 (s, 6H)

[0173]

[Chemical Formula 60]



(65)

[0174]

In addition, measurement of the thermal decomposition temperature T_d of the obtained $Ir(Fdpq)_2(acac)$ was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find T_d = 365°C, and thus, it is determined that the organometallic complex $Ir(Fdpq)_2(acac)$ shows favorable heat resistance.

[0175]

Further, FIG. 11 shows an absorption spectrum and an emission spectrum (Photo Luminescence) of the obtained $Ir(Fdpq)_2(acac)$ in dichloromethane. It is to be noted that the emission spectrum was obtained when light with a wavelength of 469 nm was used as excitation light, where the light with the wavelength of 469 nm was extracted by separating light from a halogen lamp with the use of a slit. In FIG. 11, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (a.u.: arbitrary unit). As can be seen from FIG. 11, the organometallic complex $Ir(Fdpq)_2(acac)$ according to the present invention has absorption peaks at 232 nm, 284 nm, 371 nm, and 472 nm. In addition, the emission spectrum shows luminescence with an emission peak at 644 nm, and this luminescence was visible as red luminescence.

[0176]

In the case of the obtained $Ir(Fdpq)_2(acac)$, the several absorption peaks are observed on a long wavelength side. This is absorption unique to an organometallic complex as in the case of an orthometalated complex or the like, and is believed to correspond to singlet MLCT transition, triplet π-π^* transition, triplet MLCT (Metal to ligand charge transfer) transition, and the like. In particular, the absorption peak at the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it is determined that $Ir(Fdpq)_2(acac)$ is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0177]

In addition, a gas including oxygen was injected into a dichloromethane solution including the obtained $Ir(Fdpq)_2(acac)$, and the emission intensity of $Ir(Fdpq)_2(acac)$ was examined when the $Ir(Fdpq)_2(acac)$ with dissolved oxygen was made to produce luminescence. Further, argon was injected into a dichloromethane solution including the obtained $Ir(Fdpq)_2(acac)$, and the emission intensity of $Ir(Fdpq)_2(acac)$ was examined when the $Ir(Fdpq)_2(acac)$ with dissolved argon was made to produce luminescence. From the result, it was found that luminescence derived from $Ir(Fdpq)_2(acac)$ shows the same tendency as luminescence of a phosphorescent material, where the tendency is that the emission intensity is stronger in the case of dissolved argon than dissolved oxygen. Accordingly, luminescence derived from $Ir(Fdpq)_2(acac)$ is believed to be phosphorescence.

[0178]

«Synthesis Example 2»

The present synthesis example is a synthesis example of bis(2,3-diphenylquinoxalinato)iridium(III)acetylacetonate (abbreviation: $Ir(dpq)_2(acac)$) represented by the formula (17).

[0179]

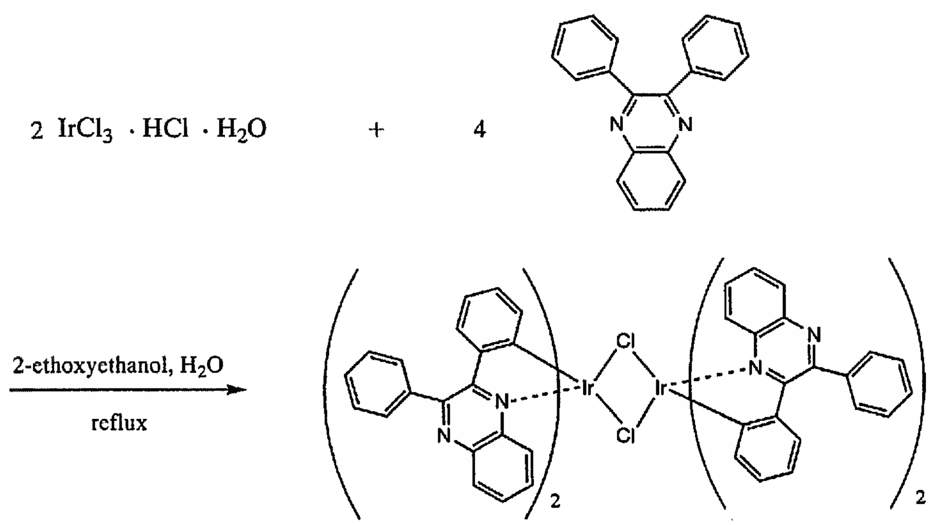
<Step 1: Synthesis of Dinuclear Complex $[Ir(dpq)_2Cl]_2$>

First, with a mixture of 30 ml of 2 - ethoxyethanol and 10 ml of water as a

solvent, 2.36 g of a ligand Hdpq (2,3-diphenylquinoxaline) and 1.00 g of iridium chloride ($IrCl_3 \cdot HCl \cdot H_2O$) were mixed, and held at reflux in a nitrogen atmosphere for 15 hours to obtain a dinuclear complex $[Ir(dpq)_2Cl]_2$ (dark brown powder, yield: 91 %). The synthesis scheme and the structure formula of the dinuclear complex $[Ir(dpq)_2Cl]_2$ are shown by the following formula (66).

[0180]

[Chemical Formula 61]



(66)

[0181]

<Step 2: Synthesis of Organometallic Complex $Ir(dpq)_2(acac)$ according to the Present Invention>

Further, with 30 ml of 2 - ethoxyethanol as a solvent, 1.00 g of the dinuclear complex $[Ir(dpq)_2Cl]_2$ obtained in Step 1 described above, 0.20 ml of acetylacetone (Hacac), and 0.67 g of sodium carbonate were mixed, and held at reflux in a nitrogen atmosphere for 15 hours. This reaction solution was filtered, and the obtained solution was purified by column chromatography with the use of a dichloromethane solvent. Recrystallization was performed with the use of a dichloromethane/ethanol solvent to obtain an organometallic complex $Ir(dpq)_2(acac)$ according to the present invention (reddish brown powder, yield: 40 %). The synthesis scheme is shown by the following formula (67). The result of analysis of the organometallic complex $Ir(dpq)_2(acac)$ by

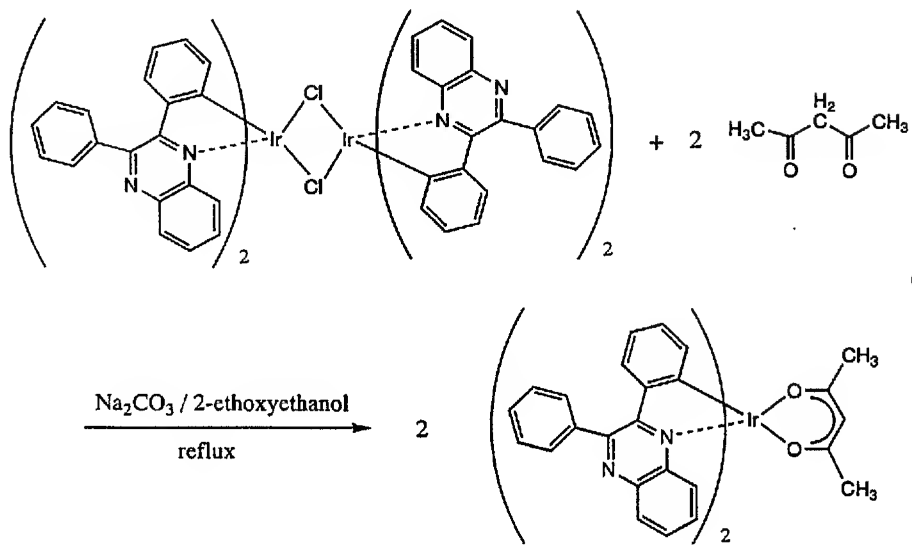
nuclear magnetic resonance (^{1}H-NMR) is as follows.

[0182]

^{1}H-NMR. δ ($CDCl_3$): 8.15 (t, 4H), 7.89 (brs, 4H), 7.79 (t, 2H), 7.69 (m, 8H), 6.94 (d, 2H), 6.57 (t, 2H), 6.48 (t, 2H), 6.33 (d, 2H), 4.81 (s, 1H), 1.64 (s, 6H)

[0183]

[Chemical Formula 62]



(67)

[0184]

In addition, measurement of the thermal decomposition temperature T_d of the obtained $Ir(dpq)_2(acac)$ was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find T_d = 340°C, and thus, it is determined that the organometallic complex $Ir(dpq)_2(acac)$ shows favorable heat resistance.

[0185]

Further, FIG. 12 shows an absorption spectrum of the obtained $Ir(dpq)_2(acac)$ in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 469 nm was used as excitation light, where the light with the wavelength of 469 nm was extracted by separating light from a halogen lamp with the use of a slit. In FIG. 12, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit),

and the right vertical axis indicates emission intensity (arbitrary unit). As can be seen from FIG. 12, the obtained organometallic complex $Ir(dpq)_2(acac)$ has absorption peaks at 248 nm, 283 nm, 378 nm, and 479 nm. In addition, the emission spectrum shows luminescence with an emission peak at 687 nm, and this luminescence was visible as deep red luminescence.

[0186]

In the case of the obtained $Ir(dpq)_2(acac)$, the several absorption peaks are observed on a long wavelength side. This is absorption unique to an organometallic complex as in the case of an orthometalated complex or the like, and is believed to correspond to singlet MLCT transition, triplet π-π^* transition, triplet MLCT transition, and the like. In particular, the absorption peak at the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it is found that $Ir(dpq)_2(acac)$ is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0187]

In addition, a gas including oxygen was injected into a dichloromethane solution including the obtained $Ir(dpq)_2(acac)$, and the emission intensity of $Ir(dpq)_2(acac)$ was examined when the $Ir(dpq)_2(acac)$ with dissolved oxygen was made to produce luminescence. Further, a gas including argon was injected into a dichloromethane solution including the obtained $Ir(dpq)_2(acac)$, and the emission intensity of $Ir(dpq)_2(acac)$ was examined when the $Ir(dpq)_2(acac)$ with dissolved argon was made to produce luminescence. From the result, it was found that luminescence derived from $Ir(dpq)_2(acac)$ shows the same tendency as luminescence of a phosphorescent material, where the tendency is that the emission intensity is stronger in the case of dissolved argon than dissolved oxygen. Accordingly, luminescence derived from $Ir(dpq)_2(acac)$ is believed to be phosphorescence.

[0188]

«Synthesis Example 3»

The present synthesis example is a synthesis example of

bis[2,3-bis(4-fluorophenyl)quinoxalinato]iridium(III) picolinate (abbreviation: $Ir(Fdpq)_2(pic)$) represented by the following formula (56).

[0189]

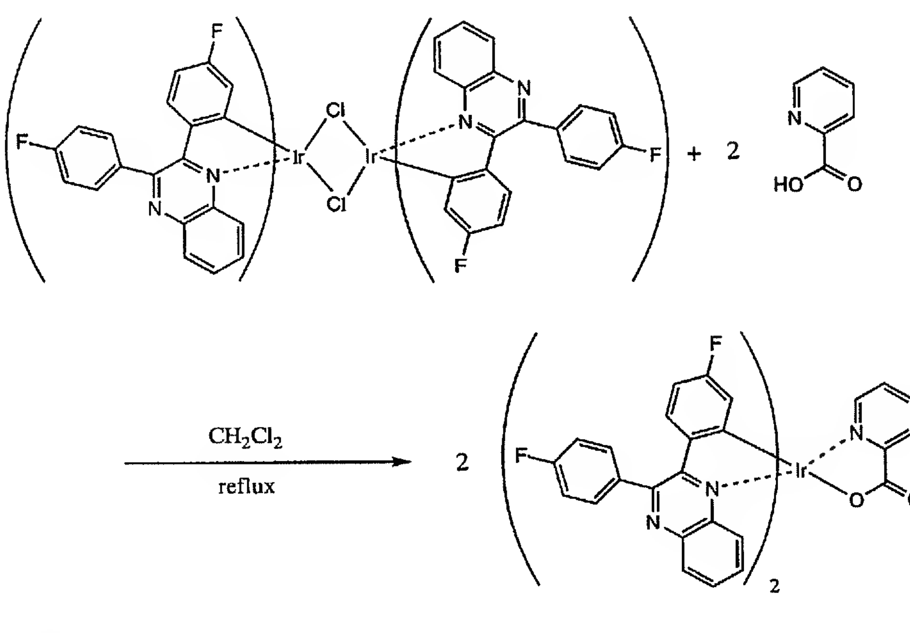
First, the dinuclear complex $[Ir(Fdpq)_2Cl]_2$ obtained in Step 2 of Synthesis Example 1 was used as a material. With 30 ml of dichloromethane as a solvent, 2.87 g of $[Ir(Fdpq)_2Cl]_2$ and 1.67 g of picolinic acid (Hpic) were mixed, and held at reflux in a nitrogen atmosphere for 16 hours. This reaction solution was filtered to obtain an organometallic complex $Ir(Fdpq)_2(pic)$ according to the present invention (red powder, yield: 56 %). The synthesis scheme is shown by the following formula (68). The result of analysis of the organometallic complex $Ir(Fdpq)_2(pic)$ by nuclear magnetic resonance (^1H-NMR) is as follows.

[0190]

^1H-NMR. δ ($CDCl_3$): 8.66 (d, 1H), 8.45 (d, 1H), 8.04 (m, 4H), 7.95 (d, 1H), 7.81 (m, 3H), 7.69 (m, 2H), 7.59 (t, 1H), 7.53 (t, 1H), 7.33 (m, 5H), 7.18 (t, 1H), 7.07 (t, 2H), 6.51 (td, 1H), 6.38 (m, 2H), 5.78 (dd, 1H)

[0191]

[Chemical Formula 63]



(68)

[0192]

In addition, measurement of the thermal decomposition temperature T_d of the obtained $Ir(Fdpq)_2(pic)$ was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find $T_d = 347°C$, and thus, it is found that the organometallic complex $Ir(Fdpq)_2(pic)$ shows favorable heat resistance.

[0193]

Further, FIG. 13 shows an absorption spectrum of the obtained $Ir(Fdpq)_2(pic)$ in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 468 nm was used as excitation light, where the light with the wavelength of 468 nm was extracted by separating light from a halogen lamp with the use of a slit. In FIG. 13, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (arbitrary unit). As can be seen from FIG. 13, the obtained organometallic complex $Ir(Fdpq)_2(pic)$ has a plurality of absorption peaks. In addition, the emission spectrum shows luminescence with an emission peak at 625 nm, and this luminescence was visible as red luminescence.

[0194]

The absorption peak at the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it is found that $Ir(Fdpq)_2(pic)$ is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0195]

«Synthesis Example 4»

In the present synthesis example, synthesis of bis[2,3-bis(3,5-difluorophenyl)quinoxalinato]iridium(III) acetylacetonate (abbreviation: $Ir(3,5\text{-}Fdpq)_2(acac)$) represented by the following formula (57) will be described.

[0196]

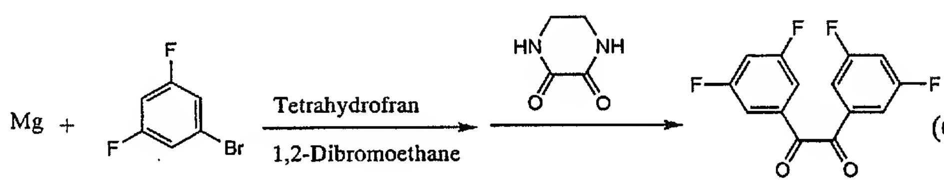
<Step 1: Synthesis of 3,3',5,5'-tetrafluorobenzyl>

3,3',5,5'-tetrafluorobenzyl that is a material for a ligand was synthesized as follows. First, 3.16 g of magnesium was suspended in 3 ml of tetrahydrofran

(abbreviation: THF), and a small amount of 1,2-dibromoethane was added. Into this mixture, a solution of 25.00 g of 1-bromo-3,5-difluorobenzene in 130 ml of THF was dropped, and stirring was performed for 1.5 hours while holding at reflux on heating. Next, 9.24 g of 1,4-dimethylpiperazine-2,3-dione was added to the solution cooled to room temperature, and stirring was performed for 13 hours while holding at reflux on heating. Further, 200 ml of 10 % hydrochloric acid was added to the solution cooled to room temperature, and the organic layer was extracted with chloroform. After drying with sodium sulfate, the solvent was condensed. Finally, purification was performed by column chromatography (hexane/dichloromethane system) to obtain 3,3',5,5'-tetrafluorobenzyl (yellow powder, yield: 46 %).

[0197]

[Chemical Formula 64]



(69)

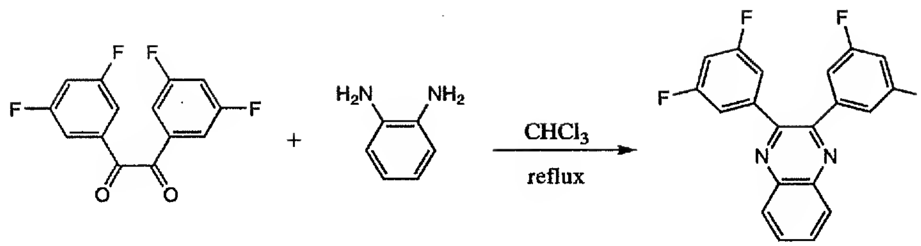
[0198]

<Step 2: Synthesis of ligand H (3, 5 - Fdpq)>

300 ml of chloroform was added to 8.32 g of 3,3',5,5'-tetrafluorobenzyl synthesized in Step 1 and 3.19 g of 1,2-phenylenediamine, and stirring was performed for 10 hours while holding at reflux on heating. The solution cooled to room temperature was washed with hydrochloric acid (1N) and then a saturated aqueous solution of sodium chloride, and dried with magnesium sulfate. Then, the solvent was condensed to obtain 2,3-bis(3,5-difluorophenyl)quinoxaline (ligand H (3,5-Fdpq)) (white powder, yield: 98 %). The synthesis scheme and the structure formula of the ligand H (3,5-Fdpq) are shown by the following formula (70).

[0199]

[Chemical Formula 65]



(70)

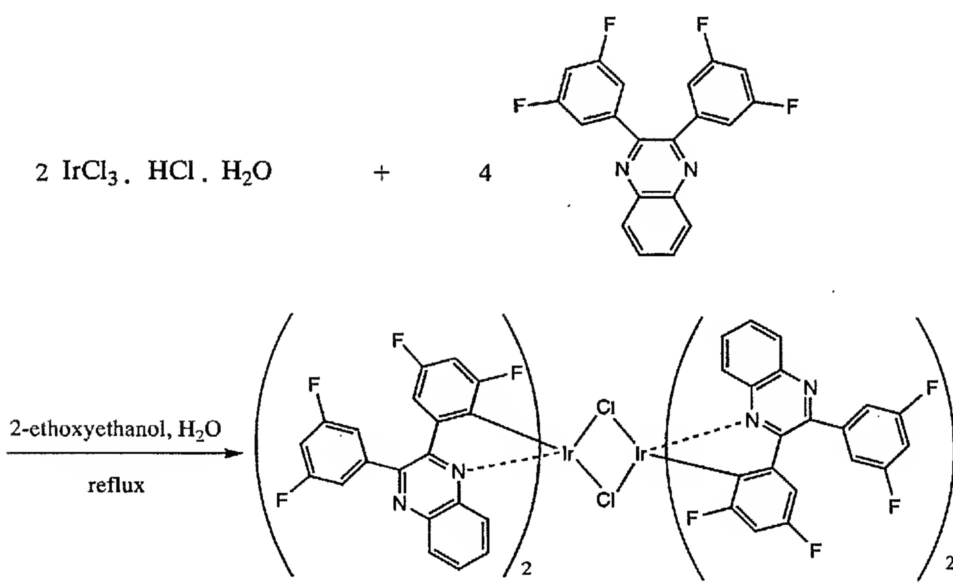
[0200]

<Step 3: Synthesis of Dinuclear Complex $[Ir(3,5\text{-}Fdpq)_2Cl]_2$>

First, with a mixture of 30 ml of 2 - ethoxyethanol and 10 ml of water as a solvent, 2.46 g of the ligand H (3,5-Fdpq) synthesized in Step 2 and 0.83 g of iridium chloride ($IrCl_3 \cdot HCl \cdot H_2O$) were mixed, and held at reflux in a nitrogen atmosphere for 17 hours to obtain a dinuclear complex $[Ir(3,5\text{-}Fdpq)_2Cl]_2$ (reddish brown powder, yield: 78 %). The synthesis scheme and the structure formula of the dinuclear complex $[Ir(3,5\text{-}Fdpq)_2Cl]_2$ are shown by the following formula (71).

[0201]

[Chemical Formula 66]



(71)

[0202]

<Step 3: Synthesis of Organometallic Complex $Ir(3,5\text{-}Fdpq)_2(acac)$>

With 30 ml of 2-ethoxyethanol as a solvent, 2.34 g of the dinuclear complex

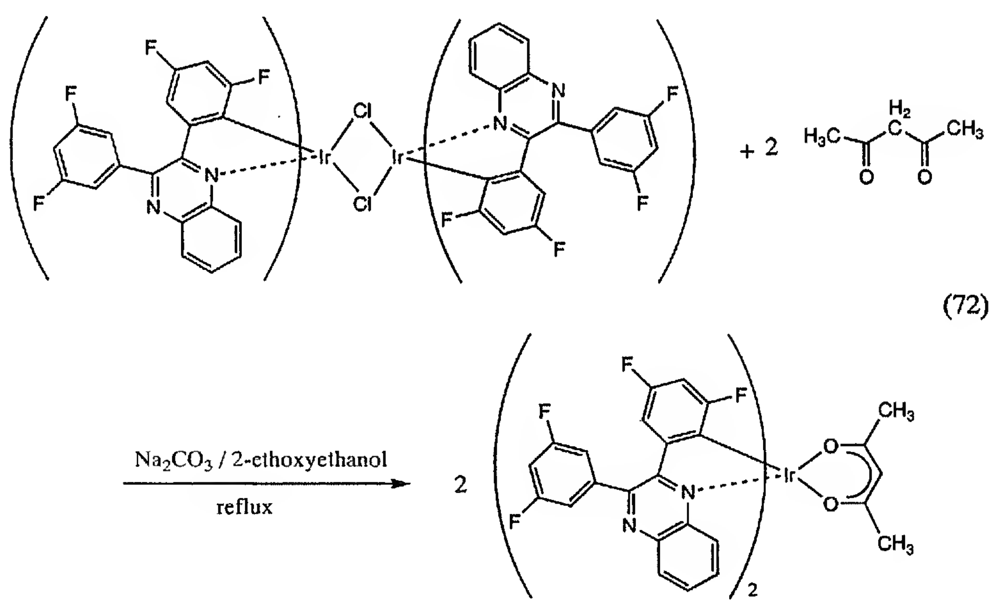
$[Ir(3,5\text{-}Fdpq)_2Cl]_2$ obtained in Step 3 described above, 0.39 ml of acetylacetone (Hacac), and 1.32 g of sodium carbonate were mixed, and held at reflux in a nitrogen atmosphere for 20 hours to obtain an organometallic complex $Ir(3,5\text{-}Fdpq)_2(acac)$ represented by the structural formula (67) according to the present invention (dark red powder, yield: 22 %). The synthesis scheme is shown by the following formula (70). The result of analysis of the organometallic complex $Ir(3,5\text{-}Fdpq)_2(acac)$ by nuclear magnetic resonance (^{1}H-NMR) is as follows.

[0203]

^{1}H-NMR. δ ($CDCl_3$): 8.10 (t, 4H), 7.75 (t, 2H), 7.61 (m, 4H), 7.30 (m, 2H), 7.09 (tt, 2H), 6.77 (dd, 2H), 6.20 (td, 2H), 4.67 (s, 1H), 1.61 (s, 6H)

[0204]

[Chemical Formula 67]



(72)

[0205]

In addition, measurement of the thermal decomposition temperature T_d of the obtained $Ir(3,5\text{-}Fdpq)_2(acac)$ was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find T_d = 342°C, and thus, it is found that the organometallic complex $Ir(3,5\text{-}Fdpq)_2(acac)$ shows favorable heat resistance.

[0206]

Further, FIG. 14 shows an absorption spectrum of the obtained $Ir(3,5\text{-}Fdpq)_2(acac)$ in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 468 nm was used as excitation light, where the light with the wavelength of 468 nm was extracted by separating light from a halogen lamp with the use of a slit. In FIG. 14, the horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (arbitrary unit). As can be seen from FIG. 14, the obtained organometallic complex $Ir(3,5\text{-}Fdpq)_2(acac)$ has a plurality of absorption peaks. In addition, the emission spectrum shows luminescence with an emission peak at 666 nm, and this luminescence was visible as deep red luminescence.

[0207]

The absorption peak at the longest wavelength side has a broad shape in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it is determined that $Ir(3,5\text{-}Fdpq)_2(acac)$ is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0208]

«Synthesis Example 5»

In the present synthesis example, synthesis of bis[2,3-bis(3,5-difluorophenyl)quinoxalinato]iridium(III) picolinate (abbreviation: $Ir(3,5\text{-}Fdpq_2(acac))$ represented by the structural formula (58) will be described.

[0209]

With 30 ml of dichloromethane as a solvent, 2.54 g of the dinuclear complex $[Ir(3,5\text{-}Fdpq)_2Cl]_2$ synthesized in Step 3 of Synthesis Example 4 and 1.34 g of picolinic acid (Hpic) were mixed, and held at reflux in a nitrogen atmosphere for 16 hours. This solution was filtered to obtain an organometallic complex $Ir(3,5\text{-}Fdpq)_2(pic)$ according to the present invention (red powder, yield: 14 %). The synthesis scheme is shown by the following formula (73). The result of analysis of the organometallic complex $Ir(3,5\text{-}Fdpq)_2(pic)$ by nuclear magnetic resonance

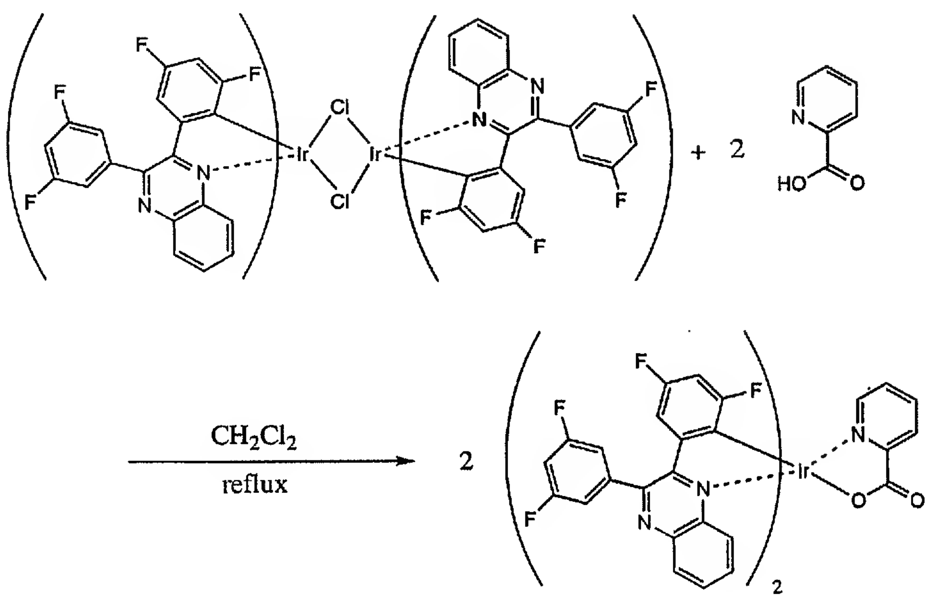
(^{1}H-NMR) is as follows.

[0210]

^{1}H-NMR. δ ($CDCl_3$): 8.65 (d, 1H), 8.54 (d, 1H), 8.06 (m, 2H), 7.87-7.54 (m, 8H), 7.32 (m, 3H), 7.12 (m, 3H), 6.85 (d, 1H), 6.74 (d, 1H), 6.37 (t, 1H), 6.17 (t, 1H)

[0211]

[Chemical Formula 68]



(73)

[0212]

In addition, measurement of the thermal decomposition temperature T_d of the obtained Ir(3,5-Fdpq)$_2$(pic) was performed by a Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320) to find T_d = 347°C, and thus, it is determined that the organometallic complex Ir(3,5-Fdpq)$_2$(pic) shows favorable heat resistance.

[0213]

Further, FIG. 15 shows an absorption spectrum of the obtained Ir(3,5-Fdpq)$_2$(pic) in dichloromethane and an emission spectrum (PL) thereof. It is to be noted that the emission spectrum was obtained when light with a wavelength of 468 nm was used as excitation light, where the light with the wavelength of 468 nm was extracted by separating light from a halogen lamp with the use of a slit. In FIG. 15, the

horizontal axis indicates a wavelength (nm), the left vertical axis indicates absorbance (no unit), and the right vertical axis indicates emission intensity (arbitrary unit). As can be seen from FIG. 15, the obtained organometallic complex $Ir(3,5\text{-}Fdpq)_2(pic)$ has a plurality of absorption peaks. In addition, the emission spectrum shows luminescence with an emission peak at 645 nm, and this luminescence was visible as red luminescence.

[0214]

The absorption peak at the longest wavelength side has a broad peak in the visible region, which is considered to be an absorption spectrum unique to triplet MLCT transition. Namely, it is determined that $Ir(3,5\text{-}Fdpq)_2(pic)$ is a compound capable of direct photoexcitation to an excited triplet state and intersystem crossing.

[0215]

The organometallic complexes described in Synthesis Examples 1 ~ 5 according to the present invention can be used as a luminescent material or a photosensitizer.

[Embodiment 2]

[0216] In the present embodiment, a light-emitting element using an organometallic complex according to the present invention as a luminescent material and a manufacturing method thereof will be described with reference to FIG. 16.

[0217]

On a substrate 850, indium tin oxide was deposited by sputtering to form a first electrode 851. The film thickness thereof was made to be 110 nm.

[0218]

Next, the substrate 850 on which the first electrode 851 was formed was fixed in a substrate holder provided in a vacuum deposition system so that the surface at which the first electrode 851 was formed was made down.

[0219]

Next, on the first electrode 851, copper phthalocyanine was deposited by evaporation using resistance heating so as to be 20 nm in film thickness to form a hole injecting layer 852.

[0220]

Next, on the hole injecting layer 852, α-NPD was deposited by evaporation using resistance heating so as to be 40 nm in film thickness to form a hole transporting layer 853.

[0221]

Next, on the hole transporting layer 853, $Ir(Fdpq)_2(acac)$ and TPAQn were deposited by co-evaporation so as to be 30 nm in film thickness to form a light-emitting layer 854. Here, $Ir(Fdpq)_2(acac)$ and TPAQn were deposited so that $Ir(Fdpq)_2(acac)$ was included at a rate of 8 weight% in a layer composed of TPAQn. This rate makes $Ir(Fdpq)_2(acac)$ dispersed in the layer composed of TPAQn. It is to be noted that co-evaporation is an evaporation method in which evaporation is performed simultaneously from a plurality of evaporation sources.

[0222]

Next, on the light-emitting layer 854, Alq_3 was deposited by evaporation using resistance heating so as to be 30 nm in film thickness to form an electron transporting layer 855.

[0223]

Next, on the electron transporting layer 855, calcium fluoride was deposited by evaporation using resistance heating so as to be 2 nm in film thickness to form an electron injecting layer 856.

[0224]

Next, on the electron injecting layer 856, aluminum was deposited by evaporation using resistance heating so as to be 150 nm in film thickness to form a second electrode 857.

[0225]

A voltage was applied to the thus manufactured light-emitting element so that the potential of the first electrode 851 was higher than the potential of the second electrode 857. Then, light was emitted with a luminance of 466 cd/m^2 when a voltage of 7.6 V was applied. The current efficiency in this case was 1.56 cd/A. Further, the emission spectrum has a peak at 652 nm. FIG. 17 shows the emission spectrum. In

addition, the element exhibits CIE chromaticity coordinates of (x, y) = (0.65, 0.33).

[0226]

As described above, a light-emitting element that is capable of providing favorable red luminescence with favorable chromaticity can be obtained by using an organometallic complex according to the present invention. In addition, when a light-emitting layer is formed by combining an organometallic complex according to the present invention with a quinoxaline derivative as the light-emitting element in the present embodiment, the organometallic complex can be made to produce luminescence more efficiently.

[0227]

It is to be noted that materials to be used for manufacturing a light-emitting element according to the present invention with the use of an organometallic complex according to the present invention are not to be considered limited to the materials mentioned above, and the materials mentioned in Embodiment mode 3 and another known materials may be used in addition to the materials mentioned in the present embodiment. In addition, the layered structure of the light-emitting element is not limited to the structure described in the present embodiment, either, and may be changed appropriately. Further, a method for manufacturing the light-emitting element is not particularly limited, either. An electrode to serve as an anode may be manufactured first as in the present embodiment, or an electrode to serve as a cathode may be manufactured first.

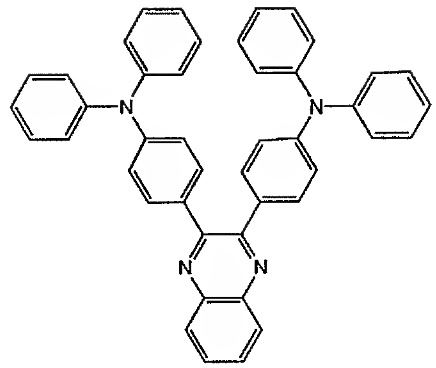
[Embodiment 3]

[0228]

TPAQn used in Embodiment 2 is a novel material. In this embodiment, a manufacturing method of a quinoxaline derivative represented by the following formula (74) will be described.

[0229]

[Chemical Formula 69]



(74)

[0230]

[Synthesis of 2,3-bis(4-bromophenyl)quinoxaline]

First, 10 g (27.4 mmol) of 4-bromobenzyl and 3.5 g (33.5 mmol) o-phenylenediamine were put in a 500 ml recovery flask, and stirred and refluxed for 8 hours in chloroform. Then, after cooling to room temperature, remaining o-phenylenediamine was removed by column chromatography to obtain 2,3-bis(4-bromophenyl)quinoxaline.

[0231]

[Synthesis of TPAQn]

Further, 4.40 g (10.0 mmol) of the obtained 2,3-bis(4-bromophenyl)quinoxaline was weighed and put in a three neck flask, and dissolved in 75 ml of toluene in a nitrogen gas stream. Then, 0.22 g (0.2 mmol) of $Pd(dba)_2$, 2.88 g (30 mmol) of NaO-t-Bu, and 3.46 g (20.4 mmol) of diphenylamine were added, 1. 8 ml of a 10 wt% hexane solution of tri(t-butylphosphine) was further added, and stirring on heating was performed at 80°C for 8 hours.

[0232]

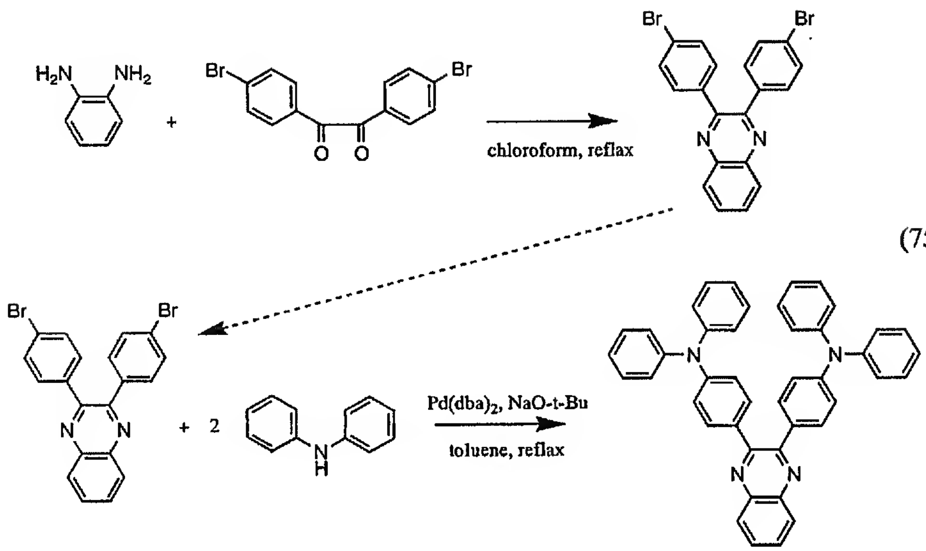
Then, after cooling to room temperature, water was added to complete the reaction, and extraction with chloroform was performed. Further, after washing with a saturated aqueous solution of sodium chloride, drying with $MgSO_4$ was performed. After that, recrystallization from the chloroform was performed to obtain 2,3-bis(4-diphenylaminophenyl)quinoxaline (abbreviation: TPAQn) (yellow-green crystal, yield: 2.7 g (44 %)).

[0233]

The synthesis scheme (75) of the synthesis described above is as follows.

[0234]

[Chemical Formula 70]



(75)

[0235]

FIG. 18 shows a ^{1}H-NMR chart of TPAQn obtained by the synthesis described above.

[0236]

Further, the thermal decomposition temperature of the obtained TPAQn was 411°C. The measurement was performed by Thermogravimetry/Differential Thermal Analysis simultaneous measurement system (from Seiko Instruments Inc., TG/DTA-320).

[Brief Description of Drawings]

[0237]

[FIG. 1] A diagram illustrating a light-emitting element of the present invention.

[FIG. 2] A diagram illustrating a light-emitting element of the present invention.

[FIG. 3] A diagram illustrating a light-emitting element of the present invention.

[FIG. 4] A diagram illustrating a light-emitting element of the present invention.

[FIG. 5] A view explaining a light-emitting device to which the present invention is

applied.

[FIG. 6] A view explaining a circuit included in a light-emitting device to which the present invention is applied.

[FIG. 7] A top view of a light-emitting device to which the present invention is applied.

[FIG. 8] A view explaining a frame operation of a light-emitting device to which the present invention is applied.

[FIGS. 9] Cross-sectional views of a light-emitting device to which the present invention is applied.

[FIGS. 10] Views of electronic devices to which the present invention is applied.

[FIG. 11] A graph showing a light emission spectrum and an absorption spectrum of an organometallic complex of the prcsent invention.

[FIG. 12] A graph showing a light emission spectrum and an absorption spectrum of an organometallic complex of the present invention.

[FIG. 13] A graph showing a light emission spectrum and an absorption spectrum of an organometallic complex of the present invention.

[FIG. 14] A graph showing a light emission spectrum and an absorption spectrum of an organometallic complex of the present invention.

[FIG. 15] A graph showing a light emission spectrum and an absorption spectrum of an organometallic complex of the present invention.

[FIG. 16] A diagram illustrating a light-emitting element of the present invention.

[FIG. 17] A graph showing emission spectrum of a light emitting element of the present invention.

[FIG. 18] A ^{1}H-NMR chart of TPAQn.

[Explanation of Reference]

[0238]

151 first electrode

152 second electrode

161 hole injecting layer

162 hole transporting layer

163	light-emitting layer
164	electron transporting layer
165	electron injecting layer
751	first electrode
752	second electrode
761	electron injecting layer
762	electron transporting layer
763	first light-emitting layer
764	partition layer
765	second light-emitting layer
766	hole transporting layer
767	hole injecting layer
771	first electrode
772	second electrode
781	electron injecting layer
782	electron transporting layer
783	first light-emitting layer
784	hole transporting layer
785	first layer
786	second layer
787	electron transporting layer
788	second light-emitting layer
789	hole transporting layer
790	hole injecting layer
181	first electrode
182	second electrode
191	hole transporting layer
192	hole injecting layer
193	light-emitting layer
194	electron transporting layer

195	electron injecting layer
6500	substrate
6503	FPC (Flexible Printed Circuit)
6504	printed wiring board (PWB)
6511	pixel portion
6512	source signal line driver circuit
6513	writing gate signal line driver circuit
6514	erasing gate signal line driver circuit
901	first transistor
902	second transistor
903	light-emitting element
911	gate signal line
912	source signal line
913	writing gate signal line driver circuit
914	erasing gate signal line driver circuit
915	source signal line driver circuit
916	power source
917	current supply line
918	switch
919	switch
920	switch
1001	first transistor
1002	second transistor
1003	gate signal line
1004	source signal line
1005	current supply line
1006	power source
501	sub-frame
502	sub-frame
503	sub-frame

504	sub-frame
501a	writing period
501b	retention period
502a	writing period
502b	retention period
503a	writing period
503b	retention period
504a	writing period
504b	retention period
504c	erasing period
504d	non-emission period
10	substrate
11	transistor
12	light-emitting element
13	first electrode
14	second electrode
15	layer
16	interlayer insulating film
17	wiring
18	partition layer
19	interlayer insulating film
5521	main body
5522	housing
5523	display portion
5524	keyboard
5551	display portion
5552	main body
5553	antenna
5554	audio output portion
5555	audio input portion

5556 operation switch

5531 display portion

5532 housing

5533 speakers

850 substrate

851 first electrode

852 hole injecting layer

853 hole transporting layer

854 light-emitting layer

855 electron transporting layer

856 electron injecting layer

857 second electrode

[Document Name] Drawings

[Document Name] Abstract

[Summary]

[Problem] It is an object of the present invention to provide a material capable of emitting phosphorescence. In addition, it is another object of the present invention to provide a light-emitting element with good chromaticity.

[Solution] An organometallic complex including a structure represented by a general formula (1). In the general formula (1), $R^1 \sim R^5$ are individually either hydrogen, a halogen element, an acyl group, an alkyl group, an alkoxyl group, an aryl group, a cyano group, or a heterocyclic group. Ar represents an aryl group or a heterocycle group. In addition, M represents an element of Group 9 or 10.

[Chemical Formula 1]